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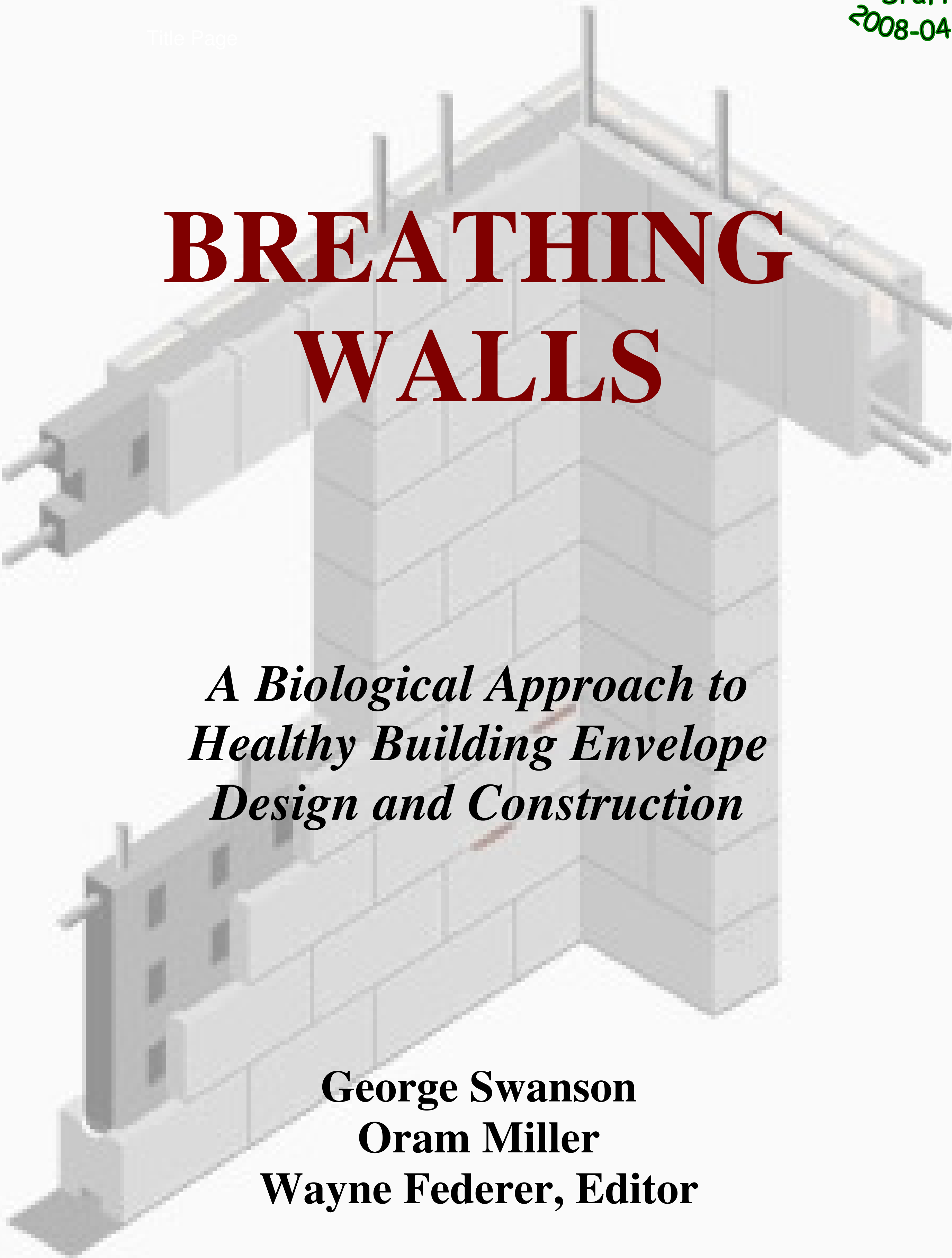

BREATHING WALLS

A Biological Approach to Healthy Building Envelope Design and Construction

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Wayne Federer, Editor

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The cover drawing, illustrating the structure of a breathable wall built with Durisol® cement-bonded wood fiber wall forms, is reproduced courtesy of Durisol Building Systems Inc., Hamilton, Ontario.

Disclaimer

The information presented in this manual is intended as a guideline only. Every effort has been made to present this information as accurately as possible as of the time of printing or electronic distribution based upon the experience of the authors, other members of the Building Biology® profession, and the building trade. However, as explained in the Editor's Note on page xviii, because this pre-publication draft version has not been 100% completed by the authors or the editor, nor reviewed by all the experts on our list, we cannot yet vouch for the truthfulness of all contents to the high level to which we aspire.

Competent architects, builders, subcontractors and homeowners are invited to use these protocols, but they must assume full responsibility for their use. Likewise manufacturers must assume full responsibility for the reliability of their products mentioned in this manual.

The authors of the individual protocols, the editor, the contributors and the International Institute for Bau-biologie® and Ecology (IBE) assume no responsibility or legal liability for the use of the protocols or products contained in this manual by builders, developers, architects, subcontractors, or home-owners.

In addition, the information presented in this manual gives general advice on those influences in the built environment that are known to be possible causes of illness. Always consult your health care provider for your individual health care needs and concerns. The information contained in this manual is presented for educational purposes only. It is not intended as a substitute for informed medical advice or care by a health care provider. You should not use this information to diagnose or treat any health problem or illness without consulting your health care provider.

Finally, it is important to note that while this manual is based upon a number of general principles of Building Biology®,[1] it is not an officially sanctioned publication of the International Institute for Bau-biologie® and Ecology. Rather it represents the collective experience as practicing building biologists of the authors and editor and those who have contributed to it, as recognized in the Acknowledgements. Aside from specific courses on the use of building materials presented in this manual, taught by author George Swanson, those wishing to learn how to implement these and other healthy building practices should seek training through the IBE in Clearwater, Florida (www.buildingbiology.net).

[1] See chapter 5, "The Basic Principles of Bau-Biologie."

Inquiries regarding requests to reprint or translate all or part of *Breathing Walls: A Biological Approach to Healthy Building Envelope Design and Construction* should be addressed to the Editor:

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The remainder of this Acknowledgments section is organized to be consistent with the structure of the book. First we try to understand the basics, then we choose materials, and finally we build homes.

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Preface

Although the term "Building (or Bau-) Biology"® has been used in Europe for over 50 years, it is relatively new in the USA. This aggregate of perennial building wisdom primarily from Europe, Asia and the Middle East was first brought to the USA by Helmut Ziehe, who completed the first translation of the German Baubiologie correspondence course for American audiences and opened the first Building Biology® center in Clearwater, Florida in 1987, now known as the International Institute of Bau-biologie® and Ecology.

At the heart of the Building Biology® philosophy is the time honored concept of the "breathing wall," that is, all natural, self-regulating, electromagnetically balanced materials that have the capacity to diffuse moisture, air and pollutants. These walls can be made using locally available, all natural materials developed over thousands of years of accumulated building practices. The Germans then took this knowledge and put the rock solid scientific data behind why these practices work so well.

The exact opposite of the concept of the "breathing wall" is the modern, "airtight" sealed building envelope so common now in this country with a suffocating airtight polyethylene vapor barrier. Fortunately it is nearly impossible to fully "seal" a building, but the closer a building gets to being airtight, the higher the probability is that the indoor air will be compromised. This combined with the toxic soup that comprises the majority of building materials used in North American has contributed to the widespread phenomenon of "Sick Building Syndrome." It is only in the last several years that the often disastrous effects of this closed, non-breathable, mechanically dependent suffocating system of construction have become apparent.

It has been estimated that in a typical $250,000 new home, a full 90% of the installed materials are in the building "shell" or "envelope." The cost to build this "shell," which includes floors, walls and the roof (and excludes doors, windows and finishes) represents on average less than 20% of the total construction cost of the building. Furthermore, less than half of this amount (about 10%) is for materials, yet this 10% of the construction budget represents 90% of the bulk of the materials of the building![2]

In no other area of construction can more be done to affordably eliminate toxins than to concentrate on this 10% dollar component of your building. Typically you can eliminate nearly all the toxins of this 90% bulk component by spending an additional amount that raises the total cost of construction by only a few

[2] For example, in a 1.5 million dollar home the ratio of raw minimal "shell" materials (minus doors, windows, and finishes) to final cost of construction may be as low as 3-4%, not 10%. High-quality, energy-efficient, nontoxic shell materials rarely cost more than 30-50% over conventional costs, adding only 1-2% to the overall cost of the house while easily doubling its energy efficiency and removing 90% of its toxins.

percent. On the other hand, getting all of the last 10% of the toxins out of your building could easily double its cost!

While attention does need to be paid to these areas, such as finish surfaces, moldings, flooring, cabinets, hardware, draperies, and furniture, in order to create a truly healthy home, it is most cost-effective to concentrate the bulk of your money and efforts on building a natural, breathable building envelope.

Improved indoor air quality through elimination of the poisons in the building envelope is only the beginning of the benefits. Superior longevity, better thermal storage qualities, better effective insulating qualities, improved fire safety, less moisture buildup and superior resistance to mold and mildew are just a few of the added benefits. In fact every recommendation in this manual offers improvement in each area mentioned above.

Building Biology® is a comprehensive and focused body of knowledge that examines the delicate balance between human health and the built environment. Through the International Institute for Bau-biologie® and Ecology, Inc. (IBE), a national network of Building Biology® professionals and training programs has been established in association with an informal worldwide network of Baubiologie centers. The IBE in North America and this worldwide network have a common goal of creating a more holistic, harmonious and sustainable habitat for humans on earth.

It is with a tempered sense of humility that the contributing authors of this manual offer this up to date North American adaptation of the time honored Building Biology® principles for building envelope design and construction as guidelines, and as at least a partial antidote to many unhealthy modern building practices.

TO A HEALTHY AND HARMONIOUS BUILDING EXPERIENCE!

Sincerely:

George Swanson, B. Sci. (Ind. Tech.)
Building Biology® Practitioner
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Co-author's Note for Pre-publication Draft 2008-04-30

After four years, we offer this pre-publication draft to those readers who have patiently waited for a written compendium of the protocols practiced by cutting edge builder and building biologist, George Swanson of Austin, Texas. It has been a privilege to put his teachings to paper. This has truly been a collaborative effort, and I want to thank my colleagues, Wayne and George, for expanding my knowledge of the field of healthy building envelopes. We present this draft of our manuscript to you, our readers, for your use and, hopefully, your review and feedback.

Please let us know your thoughts, both positive and critical. We are especially interested in the experiences of builders from around the country. Publication-quality photos would also be helpful, including examples of mold, water intrusion, the effects of common building materials, and any other topics presented that don't yet have photos to accompany them. We would acknowledge you as the provider of the photo(s).

Naturally this is a work in progress and some of the material is outdated before it even gets to the printer. We do, however, welcome the opportunity to present an alternative to the current practice of building, which for many has been a source of ill health. We will continue to update the manual in future versions.

We applaud the efforts of all those courageous builders who are "going green." You will ensure the health of our planet. This work augments that new direction by focusing on the health effects of the built environment on its occupants and ensures that as we preserve the planetary environment, we also preserve the health of ourselves and our families.

Please contact us with your feedback.

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Back in my college days in the 1970's my favorite inorganic chemistry professor had been looking for a textbook for his new class offering on an advanced topic, but none existed. But "Cube" persevered and discovered that a rather famous professor at the university where I would end up going to graduate school was actually in the process of writing one, and this guru would be quite willing to share an early pre-publication draft. So my classmates and I suffered through a semester trying to make heads or tails out of his manuscript.

Well, as if that weren't enough, the very next year my friend Stan and I ended up in the author's own class on the same topic! This time his publisher's galley proofs served as our textbook. The professor turned out to be quite friendly, with a sense of humor to match his rather large ego, and once we knew Russ we kidded him about all the errors we had found the previous year. So when our next exam was imminent he retorted that the book was in much better shape now and he would buy beer for the entire class of thirty in the unlikely event that we could collectively find a certain substantial number of errors before the test. Although never much of a drinker, I sat down with Stan and started listing errors just the two of us had marked on our copies. After less than an hour we had easily exceeded the free beer requirement for the entire class. I thought differently at the time, but looking back on the experience, from the perspective of an editor, I think the wise professor probably got the last laugh on us!

Unfortunately George, Oram and I do *not* have a captive audience of students to challenge our authority, but we *do* hope you will help us out, for we are writing a book that is on people's wish lists, with apparent demand far exceeding what existed for Russ' specialized physical inorganic chemistry text! The authors' discussions with clients and online inquiries received indicate that people are hungry for a healthy new building manual. Our sincerest desire is to get this "tool box" into the hands of aspiring new homeowners, designers and builders everywhere, before even one more "sick" building is constructed. So this editor has reined in his strong perfectionist streak and we take the somewhat unusual step of publicly releasing an incomplete draft.

In the publishing world, "pre-publication" still more often than not refers to a draft of a book that is all but ready for publication and entering the serious promotion phase. These books only need some gushy cover "blurbs" to be composed by people having impressive credentials or name recognition, while simultaneously book reviews are solicited and written by the trade journals and magazine editors to whom the book is circulated at a strategically chosen time.

However in the scholarly world in this electronic age, "pre-publication" has taken on a rather different meaning. Rather than just submit their work to their favorite scientific journal for peer review, resulting in a lengthy wait before colleagues actually see it, researchers are increasingly turning to "preprint servers" to post their work and solicit rapid feedback from their peers prior to submission for publication in a print journal. The journal editorial boards have struggled with this trend and many have (sometimes very reluctantly) altered their long-standing policies forbidding public release of information prior to publication.[3,4]

Our motivation to release this draft now is similar to that of scientists and other researchers who post their research findings online rather than following the traditional publishing model. The good news is that eBooks[5] exhaust virtually no natural resources and can be updated any number of times, offering an affordable means for you to benefit immediately from our knowledge as you design and/or build one or more healthy homes. In the process many of you may give us your valuable feedback to improve the manual before it is published.

As indicated on previous pages this is still a work in progress. Most notably, several whole sections of one chapter (chapter 8) that were less essential are missing. Of course we will remedy these omissions in our updates. Although you can now do unlimited full-text searches of our eBook[5] version, we do intend to add an index and other finishing touches. We acknowledge our manual can still be significantly improved with additional research, writing, illustration (artwork as well as high-quality photos), editing and review by carefully selected experts. Despite my meticulous approach we are still finding errors. Prior to publication we will more thoroughly scrutinize everything and make updates.

Moreover, we are only just beginning to give the book a "soul," having concentrated to date on accurately fleshing out its highly technical content. Our ultimate goal is to create a more user-friendly and visually appealing book for a wider audience than this volume is likely to attract in its present format. For example we contemplate added sidebars with quotations and interesting stories.

During our journey towards final publication we anticipate making later drafts available to you. These will be released in either eBook[5] or spiral-bound format. To learn about updates please stay tuned to the authors' websites, www.geoswan.com and www.createhealthyhomes.com.[6]

Lastly, should you wish to quote or cite this unpublished manuscript in your own publications, kindly abide by the request made in our Copyright Notice (page iv).

Happy reading!

Wayne Federer, Ph.D.
editor@breathingwalls.com

[3] The topic of preprint servers and how they relate to the publishing process is discussed on the Bioinformatics Zen blog. See posts dated June 21, 2007 to September 10, 2007: http://www.bioinformaticszen.com/tag/pre-publication/.

[4] S. P. Harter and T. K. Park, "Effects of Electronic (Pre-)Publication on Scholarly Journal Publishing: Emerging Manuscript Consideration Policies," *Proceedings of the ASIS Annual Meeting*, vol. 35, p. 438-44 (1998).

[5] We strongly encourage you consider our eBook offering. Not only does it save trees, it also may optionally be updated (see note 6) at no cost to provide you with the latest and most accurate content. Our eBook offers many features not possible in the print version: color photos, full-text searchability, bookmarks to accelerate navigation within the document, and hyperlinks that connect your web browser to online references..

[6] If we already have your email address because you either placed an order with us or inquired about the book, we will automatically notify you of updates. If you purchased the eBook, you may qualify for free updates, although this offer may change at any time.

Part One. INTRODUCTION

We begin this manual with a brief exploration of Building Biology®, the discipline providing the scientific justification for building homes with "breathing walls."

At the outset of Part One (chapter 1) we present a very brief history of twentieth-century construction in North America. This illustrates how, as society abandoned time-honored natural building materials and methods in favor of new technologies that significantly altered the physical characteristics of the structure (notably its "tightness" or "breathability") as well as the chemical composition, residents increasingly experienced significant health problems.

Next we briefly document the origins of "Baubiologie" in Germany in response to similar health challenges followed by the import of and rise of the Building Biology® profession in North America (chapter 2).

As explained in chapter 3, building biologists have much to offer homeowners and the building trade, including education and consultation on how to design and construct a healthy home. This process can be done affordably, with lasting benefits in reduced operational costs as well as high initial and retained market value.

We close our overview of Building Biology® with a discussion of how the profession's emphasis on promoting *healthy*, *bio*compatible technology complements and reinforces the "green building" approach to protecting the environment (chapter 4). We mention just a couple of instances where our recommendations differ from those commonly given by proponents of green building.

Finally, we summarize the twenty-five principles advanced by the founders of Building Biology® to guide the work of practitioners in the field (chapter 5).

Chapter 1. Historical Background

Hi folks, this is George to share a lesson from my formative years. It was 1961. My family was sitting around the kitchen table, reviewing our long-anticipated "modern renovation plans" for our not-so-vintage 1922 lath-and-plaster, asbestos "Bricktex" sided pre-WWI two-story bungalow. Already gone was the rumored original clap-board siding, the "fish-scale"cedar-shingled gable ends, the hand-carved eve brackets and the signature massive sloped front porch posts (replaced by circa 1950) spindly "wrought iron." Also, about one third of the interior cracking lath and plaster had been replaced with (gasp) "DRYWALL."

"DRYWALL!!! – the death of the building" was blurted out three times by the glassy-eyed, old Norwegian senior carpenter who was tearing out old insulation from my bedroom walls. "TRULY THE DEATH OF THE BUILDING" he authoritatively lamented as I watched the last of the old newsprint and horsehair insulation being removed from my room. At all of 11 years old, my only exposure to "DRYWALL" at that time was the stack of it that had landed on our front porch earlier that week, the stuff the old carpenter would call that "DAMN S...T" every time he would walk by. What I did know by the end of the same week was that I was certainly glad that my own room was being re-paneled in knotty pine planks, rather than DRYWALL!!!

What was the perennial, old-world wisdom the old carpenter was trying to communicate to his young, seemingly unappreciative, building associates? What hidden secret did the old-world carpenter have that seems to elude an entire generation of hastily (if at all) trained young apprentices? Was everyone under sixty in 1961 doomed to never know "The Secret"?

The occupants of a typical post-World War I "breathing wall" frame house (see Figure 1) have rarely suffered from modern "sick building syndrome." An entire generation of European old world builders were still around, however by the time the post WWI building boom started, very few of the truly old, old-world construction techniques were in general practice in North America. Even though modern "stick frame" construction had fully replaced "timber frame" and straw-clay infill, a few old-timers still carried on the tradition of using materials that had natural hydration qualities. Board & batten, clapboard or lap wood siding, stone or brick exterior were common. Lath and plaster, with the 2-inch gap between the horizontal 1-2 inch wood strips heavily plastered, was the interior wall finish of choice. Hydronic (steam radiator) heating worked especially well in conjunction with lath & plaster walls' ability to store, distribute and dehumidify itself. Roofs were commonly made of wood shakes, slate or tin. Foundations were typically stone or brick with no modern water-trapping plastic "waterproofing." These combinations achieved a good balance of thermal mass and breathability. Insulation was optional.

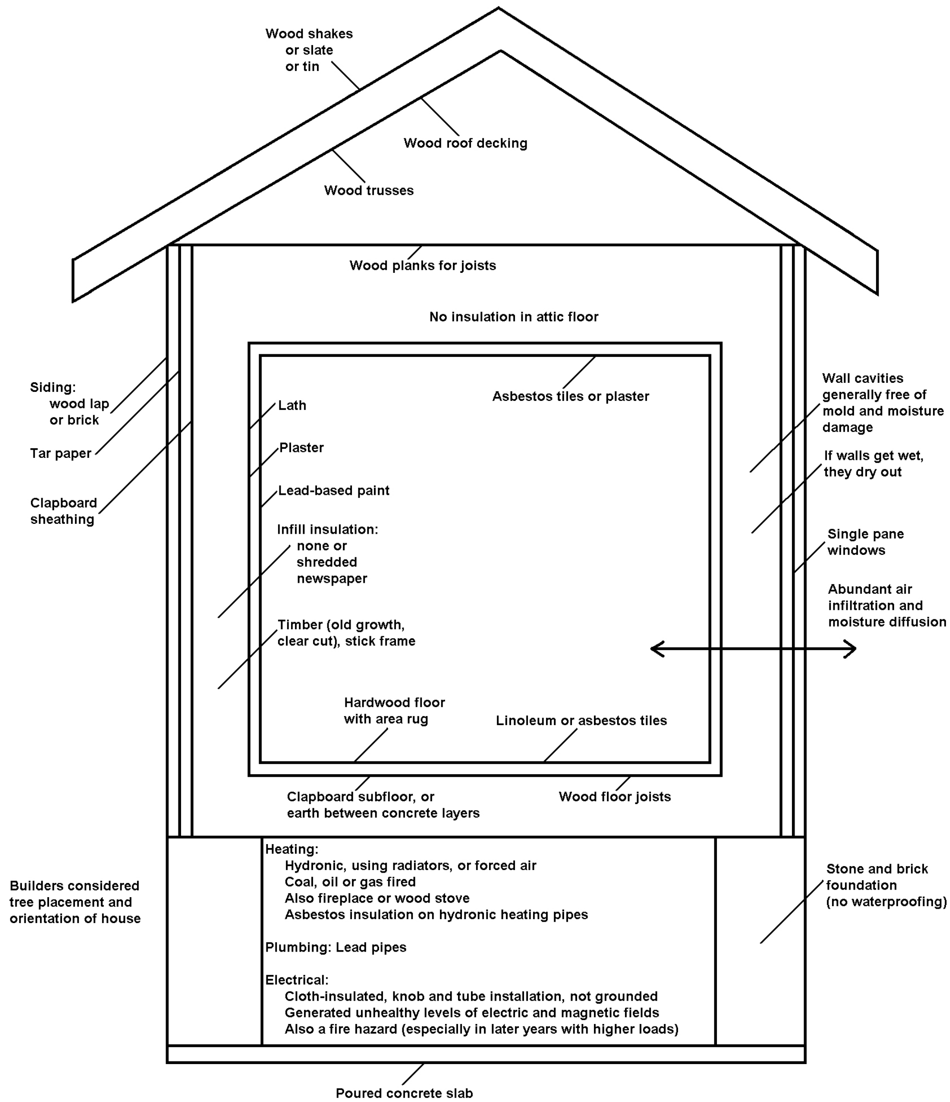

Figure 1. Typical post-World War I frame house (1920s, 1930s, 1940s)

The largest boom in North American housing took place directly after WWII. With the return of the GI's from Europe, the demand for inexpensive, rapidly build "Starter" homes skyrocketed. The typical post-WWII frame house (see Figure 2) had to be built faster and more affordably than at any other time in modern history. Lath and plaster quickly got replaced with "Drywall." The earliest version of drywall, introduced in the late 1940's, emulated many of the characteristics of lath & plaster. Typically it was over an inch thick and had approximately one-inch diameter holes drilled in it at ~12"o/c (a clear remnant from when everyone knew a wall had to "breathe"). Composition asphalt roofing was introduced but luckily was still being installed over breathing wood planks and felt paper. Foundations were now often poured concrete or "CMU" concrete block with semi-permeable tar or asphalt waterproofing. Homes of this vintage still rarely trapped water or moisture behind the walls or roof, as at least the outside wall construction was still "breathable." Also, in this era the insulation generally used was still hygroscopic. Buildings literally started deteriorating en masse with the widespread use of thin drywall (with polymeric additives) combined with non-breathable insulation (fiberglass) and non-breathable exterior sheeting (plywood or OSB). Of course, the final death blow was the ubiquitous "VAPOR BARRIER."

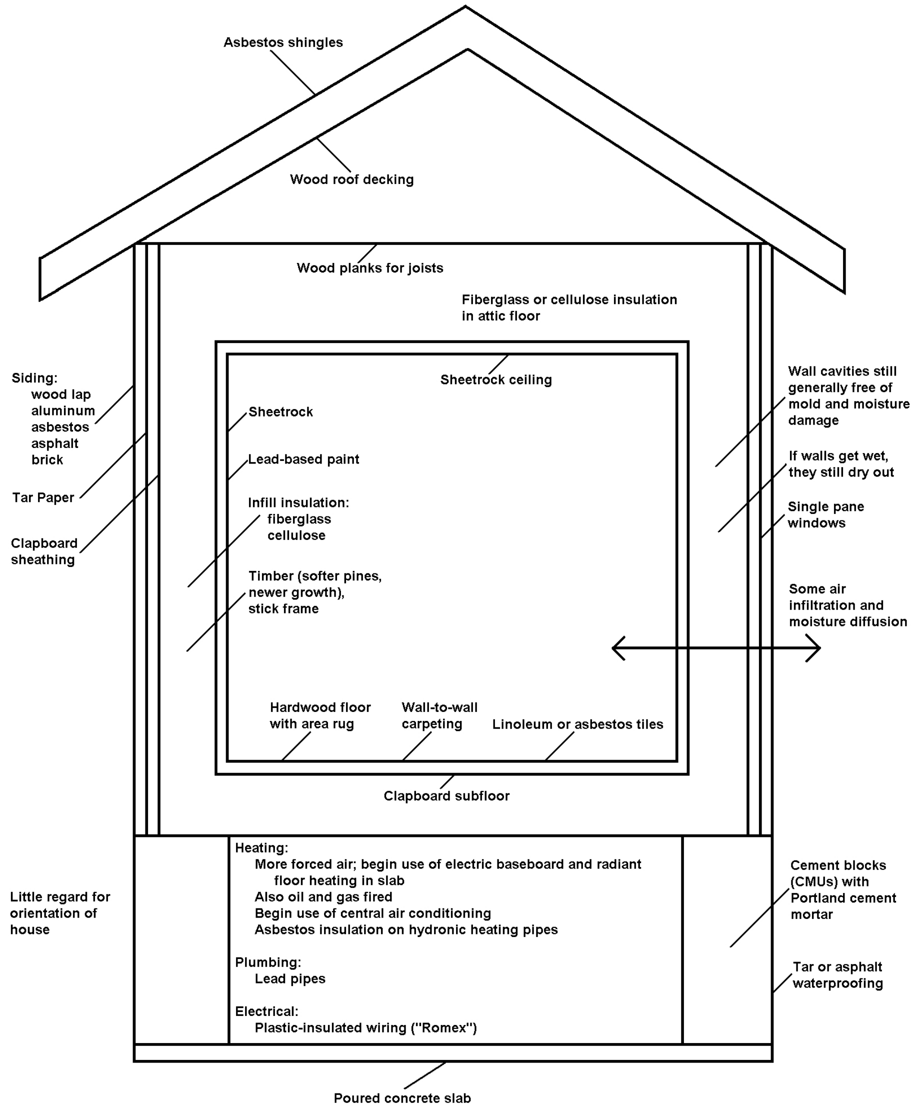

Figure 2. Typical World War II frame house (1950s, 1960s, early 1970s)

The late 1970's saw North America's first "Energy Crisis," that is, the infamous Middle Eastern Oil Embargo. With this late-dawning awareness of the utter finite nature of oil and oil-related energy products came the onslaught of "energy-efficient" building band-aids and conservation technology. (See Figure 3.) Centuries of building wisdom were literally thrown out the door in the pursuit of saving the last BTU of energy – with dire consequences!!! Sealing the building became synonymous with "SICK BUILDING SYNDROME."

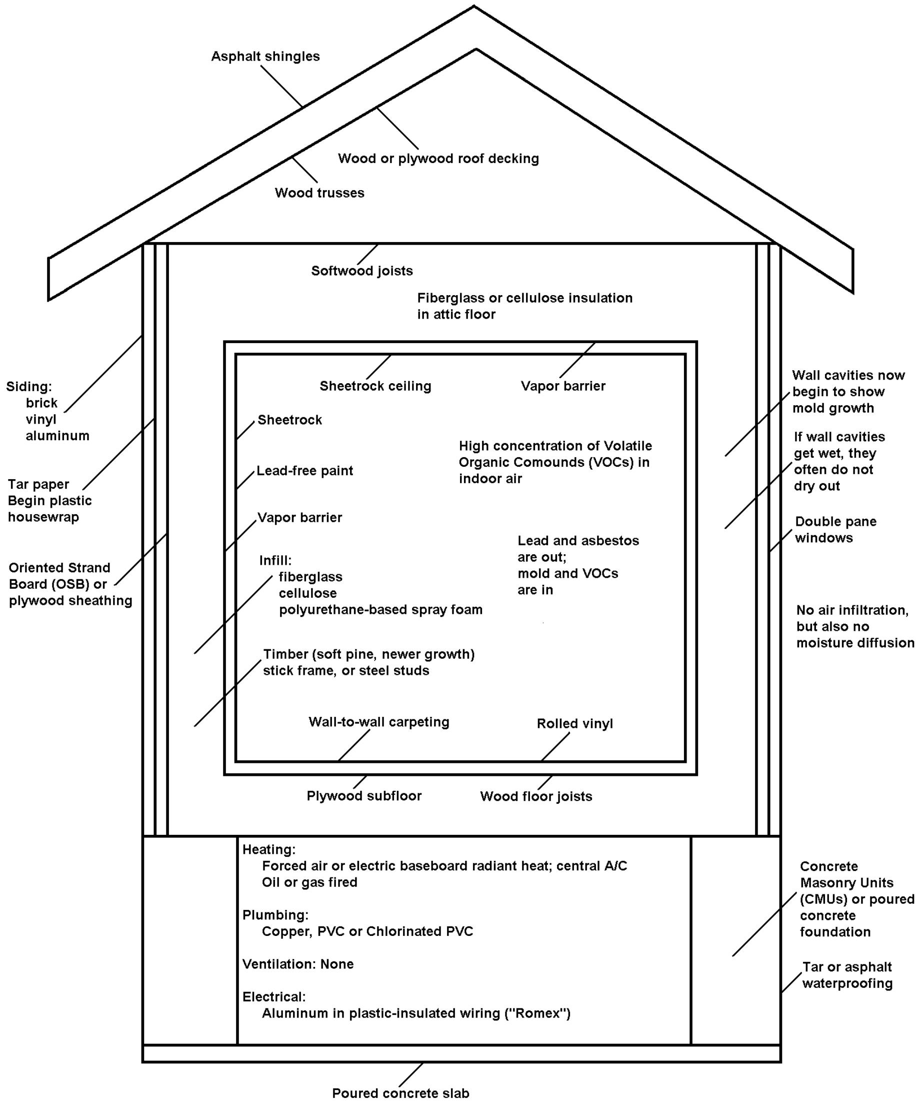

Figure 3. Typical post-oil-embargo frame house (late 1970s, 1980s, early 1990s)

Over the years, as we in the construction industry continued to tighten our building shells, we sealed in more and more of the estimated over 70,000 new chemical formulations introduced since WWII. (It is also estimated that less then one tenth of one percent of these chemicals were ever tested for human safety before being introduced into the American marketplace). Poorly breathing plywood or OSB wall sheeting were now often wrapped in non-breathing polyethylene “vapor barriers” to be finally choked in vinyl or aluminum siding!! (However, as often as not this suffocating polyethylene film was put on the inside of the wall). Slow-diffusing fiberglass insulation became the most common insulation type. Interior walls of this era were now almost exclusively polymer-laden, oxygen-challenged, modified gypsum wallboard (Sheetrock). Roofs were now nearly all poorly breathing plywood or OSB covered with slow-diffusing “composition” shingles. Add to this the widespread use of force-grown (large open cell), fast-growth lumber and a perfect recipe for mold growth was in the making. Even our basements took a hit in the beginnings of the widespread use of unproven, often water-trapping, plastic "waterproofing."

The present day "super-tight" homes (see Figure 4) add significant additional dangers to occupants by often plugging up the last opportunity for natural hydration. In addition to the suffocating features added to many of the 1970's, 1980's and 1990's homes, we've added an onslaught of questionable new ones, including Styrofoam® "out"sulation (covered with plastic stucco that may not be breathable), all plastic ICF's (Insulative Concrete Forms) and Styrofoam®- based SIP's (Structural Insulated Panels).

In retrospect, in reviewing my family's 1961 "modern renovation plans," I can now appreciate how fortunate our family was that we renovated when we did, to be spared the ravages of the whirlwind of trapped toxins, mold cultures and the formidable health risks that have become commonplace in modern construction.

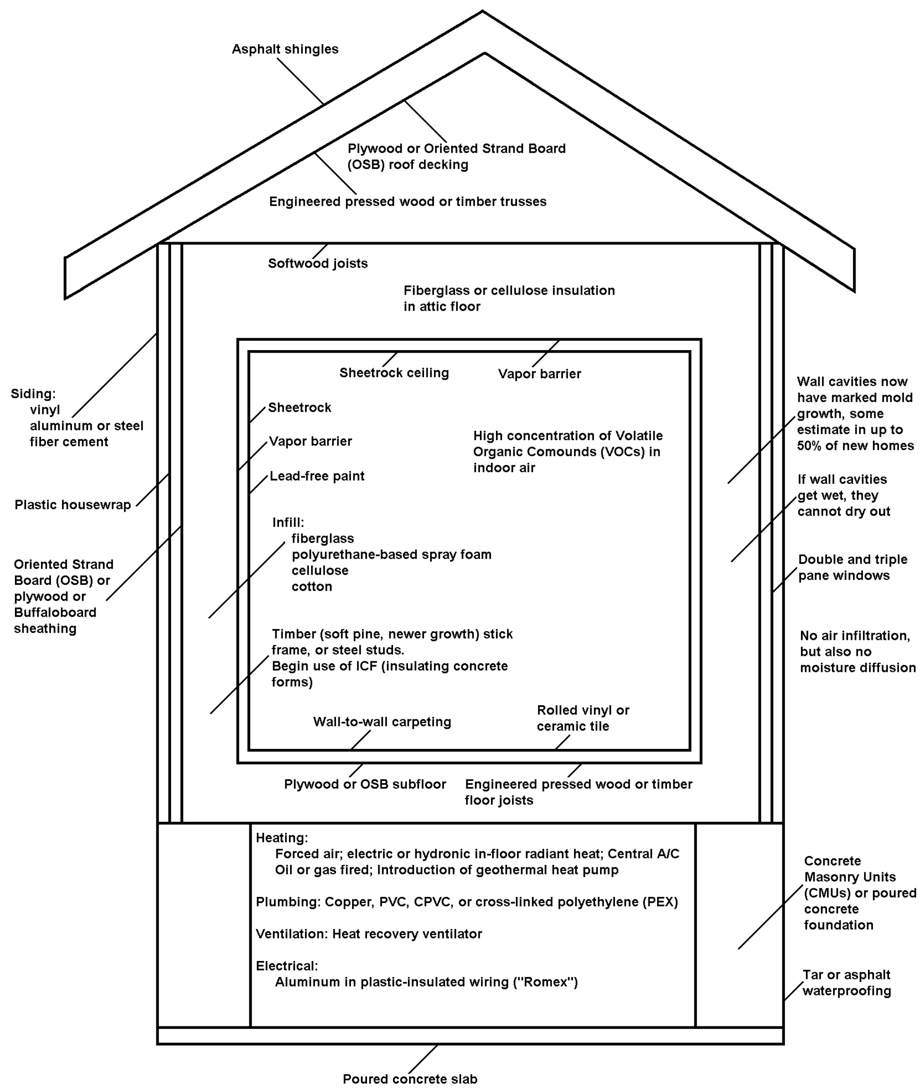

Figure 4. Typical present-day super-tight frame house (since mid-1990s)

Chapter 2. The Origins of Building Biology®

The profession known in North America as Building Biology® had its beginnings in Germany in the decades following World War II. Born of the efforts to combat the ecological devastation caused by the war and the industrialization that followed, Baubiologie, as it is known in its native Germany, has helped countless individuals over the years to restore their health and has brought healthy and natural practices back to the building trade.

The profession was brought to this country in 1987 when German architect Helmut Ziehe founded the International Institute for Bau-Biologie® and Ecology (IBE) in Clearwater, Florida. According to the Institute's website, Helmut was trained by the Technical University of Berlin in 1964 and received post-graduate training at the AA School of Architecture in London. He spent his early years in the profession studying with one of the founders of Baubiologie, Anton Schneider. Helmut has lived and worked in several countries throughout Europe as well as Central America and North Africa before coming to America. His architectural firm designed hospitals, hotels, housing units and small scale industrial developments.

Over the years several hundred students have been taught through the Institute and many have completed training and become certified Building Biology® Environmental Inspectors and Consultants (BBEIs and BBECs). This is in addition to the hundreds of practicing Bau-biologists in Europe, Australia and New Zealand. Building biologists conduct home and office evaluations for clients to find and mitigate sources of ill health in the built environment as well as to create a safe place for the compromised individual to regain his or her health. Many health care practitioners refer their clients to BBEIs and BBECs to help augment the healing modalities that they provide. Our recommendations span the gamut, from building envelopes to architectural design to materials to lighting to wiring to community planning. Besides evaluating existing buildings, we help our clients design and build healthy new and remodeled ones.

The Institute offers a wide variety of training programs and career tracks for individuals interested in learning these skills and offering their services to the general public. Contact the IBE at 727-461-4371 or log onto www.buildingbiology.net for more information.

Chapter 3. Our Offer to the Building Trade

This manual provides solutions to common problems found in today's design and construction techniques and offers an opportunity for homeowners to protect their health. Your home is your most important investment. It should be a place of healing, rejuvenation and relaxation. It should also maintain its structural integrity and value over time. Our goal is to educate homeowners and builders on why it is in their best interest to incorporate the health-promoting recommendations in this volume into the design and construction of their new homes and offices.

These approaches, based upon certain principles of Building Biology®, are compatible with the emerging "green" movement in construction and building management, which is vitally important in today's toxic and fossil fuel-depleting world. Yet Building Biology® goes beyond sustainable design, as you will see in the next chapter, by focusing primarily on the impact that buildings have on the health of their occupants. No other profession provides as comprehensive an understanding of this connection or offers such an array of practical solutions in one package.

Avoiding the Four Pitfalls in Modern Homes

Our profession's greatest desire is to encourage architects and builders to avoid the pitfalls and health challenges caused by today's construction methods. To achieve that goal, we recommend design and building techniques that avoid the four primary health problems we see in our environmental building inspections. These include occupant exposure to:

1. Mold
2. Outgassing from volatile organic compounds (VOCs)
3. Airborne particulates, such as fibers from fiberglass
4. Electric, magnetic and radio frequency fields.

Any one of these problems can produce serious health conditions, ranging from allergies, headaches, fibromyalgia and chronic fatigue to frequent respiratory infections. Even cancer is implicated, according to recent research.[7] When a combination of problems is present, the effect can be multiplied. Many homeowners don't realize their health is being compromised by their home, but they report improvement in their symptoms and energy levels when these influences are removed, even in those who are otherwise asymptomatic.

[7] David Carpenter and Cindy Sage, Co-Editors, "BioInitiative Report: A Rationale for a Biologically-based Public Exposure Standard for Electromagnetic Fields (ELF and RF)," from the BioInitiative Working Group, August 31, 2007; available at www.bioinitiative .org.

The Environmental Protection Agency (www.epa.gov) estimates that indoor air can be up to ten times more harmful than outdoor air, and poor indoor air quality ranks with inner city smog as a major source of air pollution for Americans. The introduction of synthetic fabrics and petrochemical-based synthetic compounds, combined with the oil embargo-induced tightening of walls in the 1970s, created a toxic chemical "soup" that has unleashed an epidemic of "sick building syndrome" and chemical sensitivity within our society.

The connection between sick building syndrome and the structures we live and work in is only now beginning to be understood. The tide is turning toward more nontoxic approaches to build and clean our homes. Yet for all the progress that is being made there are tens of thousands of homes built each year in North America that we consider to be too unhealthy for a large percentage of the population to safely live in. The building trade and materials manufacturers are quickly responding to market pressures to make "green" and "low-VOC" products more available.

Available Resources

If you are chemically sensitive or you are blessed with good health but don't want to become sensitive, then this and similar manuals can help you. Athena Thompson, a practicing building biologist and co-owner of Humabuilt Company (www.humabuilt.com) in Lake Oswego, Oregon, has written a book entitled *Homes That Heal (And Those That Don't): How Your Home May Be Harming Your Family's Health*,[8] published by New Society Publishers.[9] Her book educates the average homeowner on ways to make their existing home healthier. Athena has tapped into the growing interest people have in changing their habits of eating and living that don't support health and longevity. Your living and work environment is now seen not only as a potential source of ill health but also as a place to make changes. Building Biology® can help and Athena's book is a good place to start. Another recent publication, *Healthy Living Spaces,* is provided by building biologist Daniel Stih of Santa Fe, New Mexico.[10]

An important contribution to the field is the landmark healthy building manual coauthored by building biologist and architect, Paula Baker-Laporte (www.bakerlaporte.com), internist and environmental illness specialist, Erica Elliott, MD, and environmental home inspector, John Banta. The book, entitled *Prescriptions for a Healthy House: A Practical Guide for Architects, Builders and Homeowners*, is also published by New Society Publishers.[11] For a complete list of publications recommended by the International Institute for Bau-biologie® and Ecology, go to their website (www.buildingbiology.net) and click on "Find Books / Videos."

[8] See www.homesthatheal.com.
[9] See http://www.newsociety.com./bookid/3864.
[10] See http://www.hlspaces.com/HLSBook.htm.
[11] See http://www.newsociety.com/bookid/3699.

Our Contribution

The purpose of our manual is to add to the existing body of knowledge by providing specific recommendations and protocols for building a healthy home or office and for remodeling an existing one, based in large part on a number of general principles recognized by the Building Biology® profession. We focus primarily on the building envelope, including walls, slabs, foundations, attic and roof, providing an alternative to the materials and practices widely used in today's construction approaches. Those "green" approaches do provide energy efficiency, but in their efforts to keep buildings tight, modern builders create conditions for moisture to linger in walls and foundations, fostering mold.

Water Intrusion, Mold and Indoor Air Quality

For example, any wall or foundation that incorporates a vapor barrier (retarder) can produce mold sooner or later, no matter how "tight" the barrier. In fact, the tighter the wall, the less chance it has to dry when it does become wet. Besides developing mold this can lead to wood rot and loss of structural integrity. Wet walls may look fine but inside there is hidden damage and occupants are often ill for no apparent reason. The use of plastic vapor barriers in walls, ceilings and slabs is therefore avoided whenever possible throughout this manual. Alternative waterproofing materials are provided that keep liquid water out but allow moisture vapor to dry to the outside.

We also recommend thick-wall building envelopes with high thermal mass and breathability. This provides a level of health and comfort unmatched by standard wood-frame home construction, while providing equivalent or superior thermal performance. We even offer a revolutionary wood-frame protocol using natural cements that resist mold and are fully "breathable." Money is saved in fuel bills, documented by satisfied homeowners who already use thick envelopes. The reasoning behind this is explained in detail in the pages that follow.

This manual will help you improve indoor air quality while increasing your comfort at home and in your office. At the same time, operating costs can be lowered and your building can retain a higher resale value. Using these principles also preserves the structural integrity of your home and lowers health care costs. We believe the building profession on the whole needs to change its tendency to cut costs at the beginning of every project, which has the effect of sacrificing the health of occupants and the integrity of the home down the line.

It has been said that every building will have at least one water event during its life, from a leaky roof to improper flashing to condensation to a plumbing leak. Our profession asks the simple question: How will the building tolerate this inevitable event? Will walls and floors dry within the 24 to 48 hours before mold spores germinate and damp, moldy porous materials need to be discarded? Can structural damage be avoided? We offer alternatives that allow materials to dry before mold can grow while maintaining good thermal performance.

Construction and Maintenance Costs

The standard wood-frame home of today is relatively inexpensive to construct, due in large part to subsidies extended to the lumber industry. This low cost may be considered the norm but it is deceiving. You get what you pay for and end up spending more in the long run replacing damaged materials from water intrusion and mold, not to mention paying higher energy bills and health care costs. The task before us is to raise the standard of construction so that homes are built healthier to begin with and are owned by people wanting to live in them for generations, not just for a few years as an investment for resale.

Homeowners should expect to pay somewhat more to build, which slightly raises their monthly mortgage payment, but this is offset by lower monthly fuel bills and health care costs. Even with the expected rise in the cost of natural gas, propane, heating oil and electricity, homeowners who follow these guidelines will pay at worst no more than they do today, and probably far less than their neighbors.

Besides documented reductions in life-cycle costs to heat, cool and maintain your home, the size of installed equipment can be reduced with these protocols because energy requirements are less and they have a payback that offsets higher initial costs. When you also factor in the cost of health care, you end up with a lower "total cost of ownership" of your home. Families come out ahead financially and are healthier in the process.

For those new homeowners on a fixed budget, and for those builders who want to build spec houses for the entry-level market, the founder of the International Institute for Bau-biologie® and Ecology, Helmut Ziehe, has always recommended designing healthy features into houses but with a smaller footprint. He says that is what is done in his native Germany. That way you stay within your budget but do not compromise on creating a healthy, nontoxic indoor environment. Remember what George Swanson says in his Preface, that 90% of your building materials is in the envelope (walls, foundation, floor and roof), and that is where most of your toxins lie, particularly from water intrusion and mold. George says typically you can eliminate nearly all the toxins of this 90% bulk component by spending an additional amount that raises the total cost of construction by only a few percent. Seen from that standpoint, these approaches make good economic sense.

Many of the features in this manual can still be incorporated into the design of a home for a person on a fixed budget or used in the design of low-cost spec houses. Builders are encouraged to offer as many features as they can. Allow for additions later as funds permit but build a sound, breathable envelope in the first place in a smaller space. This will ensure a mold-free, well-insulated, easy-to-heat home no matter how tight the budget.

Marketing Opportunities

The recommendations contained in this manual represent a reversal of the health-threatening trends of today's mainstream home construction practices and provide a return to time-tested principles and building traditions that have served humanity for centuries, particularly in Europe. As knowledge of the perils of unhealthy homes grows within a community, people ask for healthier, more substantial materials and techniques. They are willing to pay for them once they understand the full breadth of what is offered because they appreciate the investment and cost savings over time. This trend is already happening.

As you will see in the next chapter, many of these recommendations no longer add significantly to the overall cost of construction. One or two decades ago "going green" significantly added to the budget because materials were expensive and were considered add-ons, not designed in from the start. With the growing demand in the marketplace for greener products, prices are coming down. Big box home improvement stores are carrying green product lines at comparable costs. Upfront costs for nontoxic materials and sustainable building practices are trending lower and the payback time is getting shorter. Most importantly, a sustainable house can now cost the same or even less to build than a conventional one and resale value is higher when these features are designed in from the beginning.[12]

Also see GreenClips 278, 12/21/05:

> STUDY LINKS GREEN BUILDINGS TO HIGHER MARKET VALUE
>
> A new study led by the Royal Institution of Chartered Surveyors—a global standards and membership organization for professionals involved in land, property, construction and environmental issues—shows a clear link between the environmental friendliness of a building and its market value. The international study, released in November 2005, is entitled Green Value: relating the market value of a real estate asset to its green features and related performance. It found that green buildings can: earn higher rents and prices; attract tenants and buyers more quickly; cut tenant turnover; cost less to operate and maintain; and benefit occupants. The study also noted that roughly 40 percent of carbon emissions come from buildings. So finding incentives to make buildings greener is critical.[13]

For those of you who are builders and developers, homes built according to the principles of Building Biology® and priced modestly above conventional construction can be well marketed in the USA and Canada. The interest in healthy, nontoxic construction is no longer a niche market as the number of individuals interested in these homes continues to grow. It makes economic sense to begin building with these clients in mind.

Richard Bialosky, AIA, is an experienced developer who has designed a completely nontoxic, healthy 90-home retirement community in Vero Beach, Florida (772-231-0961; richardbialosky@bellsouth.net; www.mandalaclub.com).

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[12] Alex Wilson, "Making the Case for Green Building," *Environmental Building News*, April 2005, http://www.buildinggreen.com/auth/article.cfm?fileName=140401a.xml.
[13] *The Green Business Letter*, Dec 2005, p 2, www.rics.org.

This development incorporates many Building Biology® principles. Bialosky says, "The demand for our homes has been overwhelming."

Bialosky markets his upscale development to those people who call themselves "Cultural Creatives." These individuals are known to be a highly educated, affluent population base and they value a healthy lifestyle.[14] When it comes to their homes they choose nontoxic, natural building materials, when offered.

Bialosky recently stated that surveys show that Cultural Creatives, who often think they are very much in the minority, actually number 50 million in this country, making up 26% of the US population. They also number over 80 million in Europe. He went on to say that only 1% of the nation's developers are specifically catering to this group of people. This means that 99% of developers are chasing after 74% of the market, while only 1% is pursuing 26% of the market.

Jeffrey Abramson of The Tower Companies, based in Bethesda, Maryland, is another developer who understands this approach, having led the way in offering LEED® certified, "green" commercial and residential construction in the Washington, DC area (301-984-7000; info@towercompanies.com; www.tower companies.com). Abramson states that Cultural Creatives are naturally drawn to an ecologically designed and built residential development that is also healthy, and he reports steady client demand for his properties.

It makes economic sense for the smart developer to build and promote his or her project with this upscale clientele in mind, because these people recognize the value of healthy construction that will save them money in life cycle costs and reduce demand on the earth's dwindling petroleum-based energy resources. Building their homes with Building Biology® principles in mind matters to these people and they will respond to a developer who has the same priorities they do. We predict developers will have no problem reaching a client base eager to purchase their dwellings, provided these developers inform their clients of these healthy features in their promotional materials.

Electromagnetic Fields

Finally, we will leave one of the hallmarks of the Building Biology® profession to other manuals, that is, protocols for reducing electric, magnetic and radiofrequency field exposure in homes. We do, however, touch upon this subject in relation to how mineral-based thick walls minimize occupants' exposure inside the home to unhealthy incoming radio frequencies. We also discuss protocols to avoid unhealthy magnetic field exposure caused by electric current flowing on metal rebar from the electrical grounding system. See the next chapter for a brief introduction to this important topic and how it affects people in their homes.

[14] See www.culturalcreatives.org.

Chapter 4. Our View of "Green Building"

As recently as five years ago, designing a "green" and sustainable home added 5-10% to the overall cost of construction. That figure is now down to 1-3% or less, and is actually revenue neutral when you factor in the savings in energy and water usage, according to a study of LEED® for Homes buildings.[15] Likewise with the growing interest in sustainability, resale value of "green" homes is now higher than conventionally built homes by as much as 8-15%, according to a Colorado study.

Clearly building a home in a green and sustainable way is now affordable, and whatever the increased cost or payback period, you reduce your carbon footprint immediately. This is crucial because the U.S. Energy Information Administration says that 48% of global warming is created by buildings[16], and 73% of buildings are residential homes. According to New Mexico architect, Ed Mazria, author of the Architecture 2030 Challenge, 76% of electricity generated in this country is used to operate buildings. He points out that the bulk of housing stock will be replaced by 2030 and argues that we have the knowledge now to replace those homes in a sustainable way. His challenge offers a road map for constructing new buildings in this country so that the building stock becomes carbon-neutral by 2030.[17]

To help us meet that challenge, numerous organizations exist to help builders promote sustainable, green building practices. One of those programs, LEED® for Homes, is a recent outgrowth of the success in the commercial world in designing and building sustainable properties according to guidelines promoted by the U.S. Green Building Council in Washington, DC (www.usgbc.org). LEED® stands for Leadership in Energy and Environmental Design and thousands of new and existing commercials projects have been certified by this program during the past several years across the nation. Although LEED® for Homes is a new program, the demand by residential builders and homeowners to build a LEED® certified home has exceeded all expectations.

Many regional certification programs also exist around the country. Taking into account local climatic and logistical influences, these programs have joined LEED® in raising public awareness of the need for sustainability. They are setting an example for builders and the general public to do something substantive about global climate change at a surprisingly affordable price.

The purpose of these programs is to promote energy efficiency, wise and sustainable use of resources, lower carbon emissions and waste, plan for "livable" neighborhoods, and reduce the use of water. Certification also provides rebates and discounts from mortgage lenders, utility companies, building

[15] See www.usgbc.org.
[16] See www.eia.doe.gov.
[17] See www.architecture2030.org.

materials retailers and insurance companies, as well as tax credits. Homeowners consult with their architect, builder and subcontractors to design green features into their home right from the start, economizing on the process. The biggest value, of course, is lessening your home's impact on the environment.

The Building Biology® profession supports these practices, on the whole, both as a means to reverse climate change and to improve the health of homeowners. For example, a large component of all programs is the promotion of low-VOC (volatile organic compound) paints, adhesives, cabinetry, countertops, and flooring. We applaud this step because low-VOC materials substantially reduce occupant exposure to toxic chemicals normally used in the housing industry. This has been the cause of chemical sensitivity for countless numbers of individuals.

Two examples of how we differ are in the area of how tightly you seal the building envelope and the push to replace incandescent light bulbs with compact fluorescent lamps (CFLs). Instead of continuing to make homes super-tight, we instead recommend building envelopes (walls, foundations and slabs) that "breathe" so that moisture vapor can truly escape without allowing air or rainwater to enter. The wall can dry before developing mold yet you save energy heating and cooling your home.

To reduce electricity consumption we instead recommend light-emitting diodes (LEDs) as an energy-saving alternative to CFLs, which emit agitating high frequencies due to distortion of the AC electric waveform. Many of our clients are bothered by compact fluorescent lamps. LED lights, on the other hand, generally do not emit these frequencies, and they contain none of the mercury found in CFLs. They will come down in price and third-generation LEDs are already approaching incandescent and CFL bulbs in the amount and type of light they produce.

In virtually all other ways we embrace the intent and practices recommended by green certification programs because they offer real solutions for our nation's effort to join the rest of the world in reducing our carbon footprint and saving the environment.

While these programs promote low-VOC materials, a goal we have advocated for decades, the one final area of building-related health that is not considered by them is the adverse health effects from occupant exposure to electric, magnetic and radiofrequency fields. Generated by outside overhead power lines, house wiring, household appliances, and wireless communication devices, these fields permeate our living and work spaces. Recent assessments of the potential health effects of these fields, such as contained in the peer-reviewed BioInitiative Report,[18] concluded that virtually all inhabitable space on earth is now bathed in man-made information-carrying radio frequency waves. Rather than being an innocuous influence, these fields are understood to have an adverse effect on

[18] David Carpenter and Cindy Sage, Co-Editors, "BioInitiative Report: A Rationale for a Biologically-based Public Exposure Standard for Electromagnetic Fields (ELF and RF)," from the BioInitiative Working Group, August 31, 2007; available at www.bioinitiative .org.

human health. Research and news articles abound in Europe and Canada[19] while only recently has the American media begun to cover this important subject at all.[20] (For more discussion of this issue as it relates to wireless communications equipment and what you can do to protect yourself, see section 6.9.)

For example, in response to the growing concern about electromagnetic pollution and in an effort to be proactive in all areas of building health, a green certifying organization in Minnesota has invited one of the authors of this manual and his Building Biology® colleague to submit guidelines to reduce occupant exposure to electric, magnetic and radio frequency fields in remodeled and new homes. The Minnesota GreenStar program (www.mngreenstar.org) was launched in March 2008, and the checklist for both the remodeling and new building programs contain an optional healthy wiring protocol. The protocol is offered to builders as an alternative to normal wiring practices for the purpose of minimizing occupant exposure to harmful electric and magnetic fields (EMFs) for their clients who wish to have this protection. The protocol was based upon guidelines developed by Spark Burmaster, EE, BBEI, and was updated and revised by Oram Miller, BBEI and Spark. We appreciate this interest and look forward to more collaboration between our profession and green certifying programs throughout the country on this important topic.

Following a presentation of the principles upon which our profession and this manual are based, we will begin our discussion of the desired properties of a healthy, breathable wall system.

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[19] See "Cell Phone and Radio Frequency Risks," a web page on www.createhealthy homes.com.

[20] The European Union's Environmental Agency and the government of Germany recommended in September 2007 that their citizens avoid exposure to wireless Internet (Wi-Fi) routers, cellular telephones and cell phone towers. This recommendation was based upon a thorough review[7] by scientists, physicians and policymakers (the BioInitiative Working Group), of two thousand studies documenting these deleterious effects. Researchers have come to the conclusion that the safe limits set by regulatory agencies are too lenient and advocate reducing these acceptable limits. Cancer and other health problems are often the result of long-term exposure.[7]

Chapter 5. The Basic Principles of Bau-Biologie®

The information contained in this manual is based upon guiding principles articulated by the founders of the Building Biology® profession. When Anton Schneider, Ph.D. developed the original German correspondence course, he enumerated these tenets for healthy home design local community planning. They are known in the profession as "The 25 Principles of Bau-biologie®" and are listed on the copyright-protected website of the International Institute for Bau-biologie® and Ecology (IBE).[21] A similar version is published on the English-language portion of the website of the Institut für Baubiologie und Ökologie Neubeuern (IBN) in Germany,[22] where Dr. Schneider and his progeny still practice and champion the profession. In fact, IBN also offers a large color poster for sale, graphically summarizing the principles in a very logical and attractive fashion.[23] Although in this chapter we will only paraphrase the salient aspects of the 25 Principles, we encourage the reader to review at least one of these references.

To paraphrase Schneider's Principles, they begin by emphasizing the relationship between a home and its surroundings. They recommend that one choose a site that is located away from industry and major traffic, one that is in a "geologically undisturbed" area in harmony with its natural environment.

All-natural, nontoxic building materials that are insulating and hygroscopic are recommended for walls, floors and ceilings, meaning they allow for the reversible adsorption and diffusion of water vapor. This naturally regulates indoor air humidity and filters indoor air pollutants. (Chapter 6 covers this topic in great detail.) Materials should not outgas and should have a pleasant smell. The moisture content of envelope materials should likewise be low and should dry out easily, and they should not be radioactive (as granite countertops often are, for instance).

The statements embrace the concepts of heat retention (also known as "thermal mass") and radiant heating, particularly from the sun, to provide optimal air and surface temperatures within the indoor space. (We cover these topics extensively in sections 6.6, 6.7 and 14.6.) More subtle effects not normally considered in the design of today's housing developments are also considered. These include lighting, color, acoustic dampening, and preserving the natural balance of negative and positive ions while avoiding the buildup of static electricity in the indoor living space.

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[21] See http://www.buildingbiology.net/25profba.html.

[22] See http://www.baubiologie.de/site/english/principles.php.

[23] A non-printable version of the IBN poster, entitled "Natural Building = Healthy Building," may also be downloaded from http://www.baubiologie.de/site/shop/plakate/naturalbuilding.php. A second IBN poster, entitled "Building Biology Master Communities," also summarizes many of the Principles: http://www.baubiologie.de/downloads/shop/ENG_oekodorf.pdf.

The existence of natural, beneficial geomagnetic fields under houses is recognized and one of the principles conveys the opinion that these terrestrial fields that accompanied the evolution of our species should not be altered or disturbed. Likewise the authors assert that there are positive health effects of exposure to natural radiation from the earth and from outer space and recommend against using materials (primarily metal roofs) that block this beneficial effect.

Building biologists universally recognize the harm produced by man-made electric and magnetic field exposure, including artificial information-carrying radio frequencies, such as from cell phones, cordless telephones and wireless Internet (Wi-Fi) routers. This topic was touched upon in the previous chapter, and section 6.9 explains how using the right materials for the building envelope can protect against this "electrosmog."

Schneider's Principles recognize the ergonomic effect of furniture design on occupants and consider the effects of proportion and shape within the design of the interior space. In that respect, the Building Biology® profession is in keeping with ancient traditions, such as China's Feng Shui and India's Sthapatya Veda, or Vastu. (See section 14.9)

Finally, Baubiologie preceded the modern-day green and sustainable movement by several decades in supporting the use and disposal of materials so as to avoid environmental pollution and utilize renewable resources. The profession even considers the effect the building trade has on medical costs to society by recognizing early on the health effects associated with what is today called "sick building syndrome."

Part Two. THE BREATHABLE BUILDING ENVELOPE

A healthy building envelope, consisting of slab, foundation, walls and roof, is the heart of a healthy home. Therefore we devote Part Two to a detailed exploration of this topic.

To understand how a building envelope works, especially an unconventional one such as the so-called "breathing wall" system that building biologists recommend, we begin by providing the necessary scientific background (chapter 6).

Having grasped these concepts, the reader is well equipped to understand the problems associated with water intrusion and how it affects conventional construction. You will learn the ways in which breathable and thermally massive wall systems handle these problems in a completely different way, greatly reducing the ability of mold to grow in walls and foundations (chapter 7).

Next we describe our preferred wall materials that satisfy our design criteria. Practical technologies readily adaptable by the mainstream construction trade in North America are our focus (chapter 8). Cements are integral to several of these systems, so this discussion also addresses the search for healthier alternatives. Finally, we present breathable, thin-wall alternatives to conventional wood-based sheathing, using magnesia, a raw material that is readily available throughout the world. Cavity insulation materials that allow rapid drying of moisture without creating mold are installed into these thin walls.

Now that we have learned how to select our breathable materials and what our choices are, we are ready to begin building! The hands-on aspects of constructing the complete wall system, including all finishing treatments, are explained in chapters 9 and 10 for thermally massive and alternative thin-wall materials, respectively. The remainder of the envelope, consisting of slab, foundation, roof and attic, is presented in chapters 11 to 13. (The detailed construction protocols are saved for Part Two.)

Having finally surrounded ourselves with a breathable envelope, we conclude Part Two by putting forth some additional design considerations necessary for the envelope to function well: moisture control; ventilation; passive solar; windows and doors; heating and cooling (chapter 14). We even discuss how Building Biology® interrelates with such ancient building traditions as China's Feng Shui and India's Sthapatya Veda, also known as Vastu.

Chapter 6. Desired Properties of a Wall System

6.1 Introduction

A wall should not just be an enclosure. It provides far more than just protection from the elements. An appropriately designed and constructed wall is a fundamental part of the home and has far-reaching impact on the health of occupants.

A properly constructed wall should be designed to provide the following benefits:

1. Self-regulation of moisture year round.
2. Storage of heat in winter and cool in summer.
3. Optimally-phased distribution of heat and cool.
4. Radiant heating and cooling.

These benefits are achieved by judicious choice of materials and smart design. Materials should be breathable, allowing what moisture that inevitably does enter a wall cavity to be transported through it in the form of water vapor. Superior thermal performance must not be compromised.

A healthy, ecological wall should ideally incorporate three design elements:

1. Heavy thermal mass towards the inside of the wall
2. Medium core in between
3. Lighter "out"sulation as the outer layer (thicker in northern climates)

From the standpoint of the entire dwelling, the wall and foundation systems recommended in this manual not only possess these characteristics, but they fulfill most of the 25 goals of the Building Biology® profession described in chapter 5 even before additional aspects are considered. This is because the envelope of a house, that is, the floors, walls, and ceiling, is the single greatest component affecting the health of its occupants. If you use the relatively inexpensive mainstream methods of today to build your envelope, then you can expect some degree of "sick building syndrome." If, on the other hand, you invest in a healthy building envelope as described in this manual, you are well on your way to preventing and avoiding many of the sources of building-induced illness that have plagued home and business owners in modern industrial society for decades.

This chapter will fundamentally cover all of the desirable properties of a wall system: vapor permeability, hygroscopicity, capillarity, thermal mass, "out"sulation, radiant heat transfer, structural integrity, and the subtle energies associated with using natural materials. It is also often desirable to build an envelope that protects the occupants from incoming radio frequencies from outside broadcast sources such as TV, radio, pager, cell phone and wireless Internet (Wi-Fi) antennas. But first we introduce the reader to "breathability," which encompasses the first three of these properties and is of paramount importance.

6.2 What is a "Breathing Wall?"

In the 1850's a professor named Max von Pettenkofer studied the permeability of air and moisture through porous building materials, by blowing out a candle from the opposite side of a wall.[24] One hundred years later the man sometimes referred to as "the father of Building Biology®," a German medical doctor named Hubert Palm, popularized the term breathability (Atmungsfähigkeit).[25] Early building biologists promoted the idea of a "breathing wall."

As properly understood, the "breathing wall" is an extremely important concept for high indoor air quality and mold-free construction. Unfortunately some people (both laypersons and professionals) interpret the expression literally, as if we are saying these walls have lungs. To avoid such confusion this writer puts the term in quotation marks. The terms "breathable" and "breathability" are preferable, as they indicate a passive rather than an active function. Moreover, common parlance (at least in English) uses "breathable" to describe such materials as Gore-Tex®, the porous fabric designed to pass water as vapor but not liquid. Nevertheless, as explained in the remainder of this chapter, breathability in buildings is considerably more complex!

The authors of this manual are among the relatively few American building biologists involved in new construction and the design of building envelopes and therefore they work with the concept of breathability. However to obtain a broader perspective the editor queried two dozen European building biologists, scientists, designers and architects concerning "breathing walls."

These correspondents expressed many different viewpoints on the topic. Our distillation resulted in an appreciation that breathable wall systems actually incorporate several different physical properties that are fundamental to healthy home construction. Building scientists refer to these as *hygrothermal* properties, as all of the related phenomena involve in some way the transport of moisture:

1. Permeability and diffusion
2. Hygroscopic adsorption/desorption
3. Capillary absorption/desorption

Each of the following sections will explain one of the above types of breathability and why it may be essential for a healthy building envelope. We

[24] Max von Pettenkofer, "Sur le comportement de l'air au logement de l'homme" (On the behavior of the air in human abodes), Brusnwick 1877. For a very brief description of this work, see http://de.wikipedia.org/wiki/Atmende_Wand.
[25] Hubert Palm, *das Gesunde Haus* (The Healthy House), Tenth edition, © Ordosan AG; Kösel, Kempten (1992), pp. 84-85. The first edition was published in 1968. *[The date may actually be earlier and we are trying to find out. –Ed.]*

thank Neil May of Natural Building Technologies in the UK for his enlightening online manuscript that rather thoroughly explains these concepts as well as their application. His paper, entitled *Breathability: The Key to Building Performance*, was extremely helpful in writing the next three sections and can be found online.[26]

6.3 Vapor Permeability and Diffusion

Vapor permeability is a property reflecting the rate of movement of water molecules, H_2O, directly *through* a material. It should not be confused with *infiltration*, which is leakage through gaps *between* separate pieces of material. Rather, permeability is determined by the openness of the physical structure *within* the same material, such as wall board, insulation or a vapor barrier. Moisture transport due to permeability is usually small compared to that from infiltration and ventilation, wherein the major water vapor transport mechanism is its movement in flowing air. However, as we shall see below, permeability in the right kind of materials does play a profound role in allowing moisture to escape from building materials before mold formation becomes a problem.

The physical process responsible for vapor permeability of a building envelope is called *diffusion*. Matter is transported spontaneously as a result of the intrinsic kinetic energy and random thermal motion of molecules. Within a gaseous medium such as air the individual molecules mix and redistribute. There is no bulk flow; that is, no net transfer of mass to or from any region of interest.

Diffusion of moisture in air involves movement of water molecules as well as the molecules of oxygen, nitrogen, and minor components such as carbon dioxide. Net diffusion is driven by a gradient of airborne water vapor concentration or H_2O partial pressure. Water molecules dissolved in the vapor phase are spontaneously transported from volumes of higher concentration to those of lower concentration, until the concentration is uniform. This slow process is affected by both temperature and pressure.

The reader will hopefully gain a better understanding by looking at the illustrations in Figure 5 on page 26. In the initial phase of diffusion, the molecules of different gaseous components are far from equilibrium. In the extreme, simplistic case that is illustrated, let us suppose that *all* of the molecules inside the "home" are water vapor (**O**) and that all of the molecules outside are oxygen (●), just one component of air. (Of course, there is no such thing as an "air" molecule!) As diffusion proceeds (intermediate drawing), water molecules begin to move outside and are replaced by oxygen molecules moving inside. Finally, if and whenever the system reaches equilibrium, all of the molecules are uniformly distributed although still moving randomly.[27]

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[26] Neil May's article was last accessed in April 2008, when it was found at http://www.greensteps.co.uk /tmp/assets/1163178050906.pdf.
[27] In the real world we seldom if ever attain equilibrium because the outside humidity, temperature and pressure are continually changing.

Vapor permeability is an intrinsic material property. In the United States we generally consider the related property of permeance, which is dependent upon the thickness of the material much like the R-value in heat transmission. The building industry rates different materials in units of perms. One perm corresponds to the passage of 1 grain of water vapor through 1 square foot of building material in a period of one hour under a pressure differential of 1 inch of mercury.[28] Building scientist Joseph Lstiburek has proposed[29] that materials be classified into four categories based on their vapor permeance:

Impermeable (Class I Vapor Retarder)	≤ 0.1 perm
Semi-impermeable (Class II Vapor Retarder)	0.1 to 1
Semi-permeable (Class III Vapor Retarder)	1 to 10
Permeable	> 10

These classes are then referenced in local building codes throughout the country to set the standard for maintaining thermal performance in the local climate. Building code in the Minneapolis area, for example, requires that builders achieve a Class II rating, though this can be accomplished a number of ways, not exclusively through the use of a sheet of polyethylene as a vapor barrier – see below.

Typical permeance values for a sampling of building materials from a variety of sources are listed in Table 1.[30,31] As explained in the footnotes, permeance varies with humidity and this table includes both wet cup and dry cup values, suitable for use in different climates.

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[28] Common metric units for permeance are ng/Pa·s·m^2. To convert to perms, divide by 57.2. Alternatively, in the United Kingdom they use *construction resistance* (in units of 10^3 ·Pa·s·m^2/ng or equivalently 10^6·N·s/g), which is inversely proportional to permeance. On the European continent the vapor resistance is often reported as a μ value that has been normalized to the value for a one-meter thickness of air, for which μ =1. (The construction resistance of air is approximately 5 x 10^6·N·s/g.)

[29] This proposal is found in a document entitled Understanding Vapor Barriers on Lstiburek's website: http://www.buildingscience.com/resources/3-Understanding_Vapor_Barriers.pdf. He references the February 2002 *ASHRAE Journal* for a preliminary discussion related to his proposal.

[30] For the laboratory measurement, a sample of the material is sealed onto a shallow metal cup placed inside a constant-humidity (50% RH), constant-temperature (73.4 °F) chamber. In the dry cup method, the cup is filled with a desiccant that draws water vapor through the sample and into the cup, in which the airspace is maintained close to 0% RH. The permeability or permeance is proportional to the rate of weight gain. In the wet cup method, the cup is partially filled with water, creating a 100% RH airspace above the water level, from which water vapor is sucked through the sample into the chamber. The permeability or permeance is proportional to the rate of weight loss. Wet cup measurements usually result in a higher permeance than dry cup, for permeability values increase with humidity. Which method is appropriate depends on the application of the material. The dry cup method is specified for materials such as vapor barriers intended for dry environments. The wet cup method is more useful for evaluating more vapor permeable materials that may be exposed to high levels of moisture. [Much of this information was taken from the Sto Corporation's Tech Hotline No. 0806-BSc, found at http://www.stocorp.com/webfiles.nsf/htmlmedia/vapor+barriers.pdf.]

[31] As measurement conditions are as often as not unspecified, we have taken great liberty in creating this table, which is intended merely as a rough guide. Some of these data are for dry cup, others for wet cup. Taking into account the measurement conditions is

Table 1. Water Vapor Permeance of a Variety of Building Materials

Material description	Permeance (perms)
Polyethylene vapor barrier, .004-.006 in.	0.03
Aluminum foil, .0035 in.	0.05
Vinyl wall paper	0.09
Exterior oil-based paint, 3 coats	0.3 to 1.0
Extruded polystyrene, 2 in.	0.3
Vapor retarder paint, 1 coat = 0.003 in.	0.5
Cement plaster, 1 in.	1.2
Expanded polystyrene, 2 in.	2
Brick, 3½ in.	3 to 4
Oriented strand board, 3/8 in.	2 to 5
Latex paint (primer and sealer)	2 to 6
Concrete block, 8 in.	2.4
Hardwood (oak, ash, beech), solid, unfinished, ¾ in.	2
Plywood, 3/8 in.	2 to 9
Softwood (spruce, pine, fir), solid, unfinished, ¾ in.	4
Synthetic top coat plaster, 1/8 in.	4
Traditional stucco, 7/8 in.	4 to 7
House wrap (in good condition)	5 to 50
Autoclaved aerated concrete	5
Icynene® spray urethane insulation	5
Fiber-cement lap siding, primed all surfaces*	5*
Wood fiber insulation board (“wood wool”), 4 in.	7
Clay board (Claytec®), 1 in.	9
Lime plaster, 1 in.	17
Low-density cement-bonded wood chip block (Durisol®), 1 in.	14 to 17
Cellulose insulation, 3½ in.	21
Clay plaster, ¾ in.	23
Building paper, asphalt-impregnated felt	30
Wood lap siding, 3/8 in., unfinished*	10 to 35*
Fiberboard, asphalt-impregnated	34
Fiberglass or rockwool insulation, 3½ in.	35 to 48
Vinyl lap siding*	40 to 70*
Gypsum drywall, standard paper-faced, ½ in.	75
Air, 1 in.	120

* This value is an “*equivalent* vapor permeance” based on actual *wall* conditions, including the leakage between siding joints. Note the actual solid siding materials are far less permeable!

We have taken artistic liberty in Figure 5 an effort to clearly illustrate the *concept* of diffusion. The sketches accurately depict the mixing of pure gases. In a more realistic rendering of the building moisture application, there would already be a large degree of mixing at the outset. Moreover only about two percent of the molecules in water vapor-saturated indoor air (100% RH at 68 °F) are actually H_2O. Depending upon the temperature, outdoor air at 100% RH contains

particularly important for hygroscopic materials (see next section), for which the permeance increases significantly with relative humidity.

anywhere from about 0.1% H_2O (at 0 °F) to about 5% H_2O (at 95 °F). So under any realistic conditions at least 95% of the molecules are oxygen or nitrogen.

The *rate* of diffusion through a material is determined by the pore structure, often referred to as microstructure. The process becomes significantly hindered at pore diameters of less than about 0.05 microns, which is less than one hundredth the diameter of a human hair.[32] Still about one hundred water molecules will fit at the mouth of a 0.05 micron diameter pore. Progressively slower diffusion occurs through orifices smaller than 0.002 microns.

The movement of water vapor should not be confused with the flow of air. The two are not even necessarily in the same direction! Water movement is more often than not from inside to outside of the building envelope, due to vaporization of moisture produced by the daily activities of living, such as showers and cooking, use of combustion appliances (gas furnaces and hot water heaters), and respiration of the occupants. Air pressure, on the other hand, results from wind and temperature differences and can vary throughout a building depending upon the wind direction and related factors. (Mechanical ventilation, if used, produces negative indoor pressure.)

As a practical matter, vapor permeability due to H_2O diffusion through breathable walls plays only a very minor role in supplying the fresh outside air necessary to make a building comfortable and healthy during the course of a day. Our section on natural ventilation in chapter 14 explains that a whole-house air exchange rate from at least several tenths up to one air change per hour (ACH) is commonly required. (Of course, simultaneously the same rate of moisture exchange is achieved.) When queried by the editor, experts such as building scientist John Straube (University of Waterloo, Waterloo, Ontario, Canada) and designer-builder Lou Host-Jablonski (Design Coalition, Madison, Wisconsin) have estimated that a tightly built but breathable structure provides no more than a few hundredths of an ACH on its own. Since this is several times less of an air exchange than is commonly required, we recommend that supplemental ventilation be provided. Chapter 14 discusses how we recommend achieving that using a combination of conventional and unconventional approaches.

The relatively low level of natural air exchange directly through a breathable wall does help us, however, with respect to modern construction's persistent problem of mold formation. For us to better understand how this happens, consider what happens when a wall gets wet by rainwater leakage or internal condensation.

First we should point out that, as will be detailed in the next chapter, theoretically the use of a vapor barrier will seal a wall from moisture intrusion, but in practice building biologists and many in the building industry have found that this is rarely the case. Improper installation or care leads to discontinuities or punctures in the barrier. Trapped moisture and potentially hazardous mold formation are often the result, not to mention structural damage.

[32] This diameter corresponds to the mean distance that a molecule travels in between intermolecular collisions. Here molecules start hitting the pore walls before they hit other molecules, so that the pores start slowing down the diffusion process.

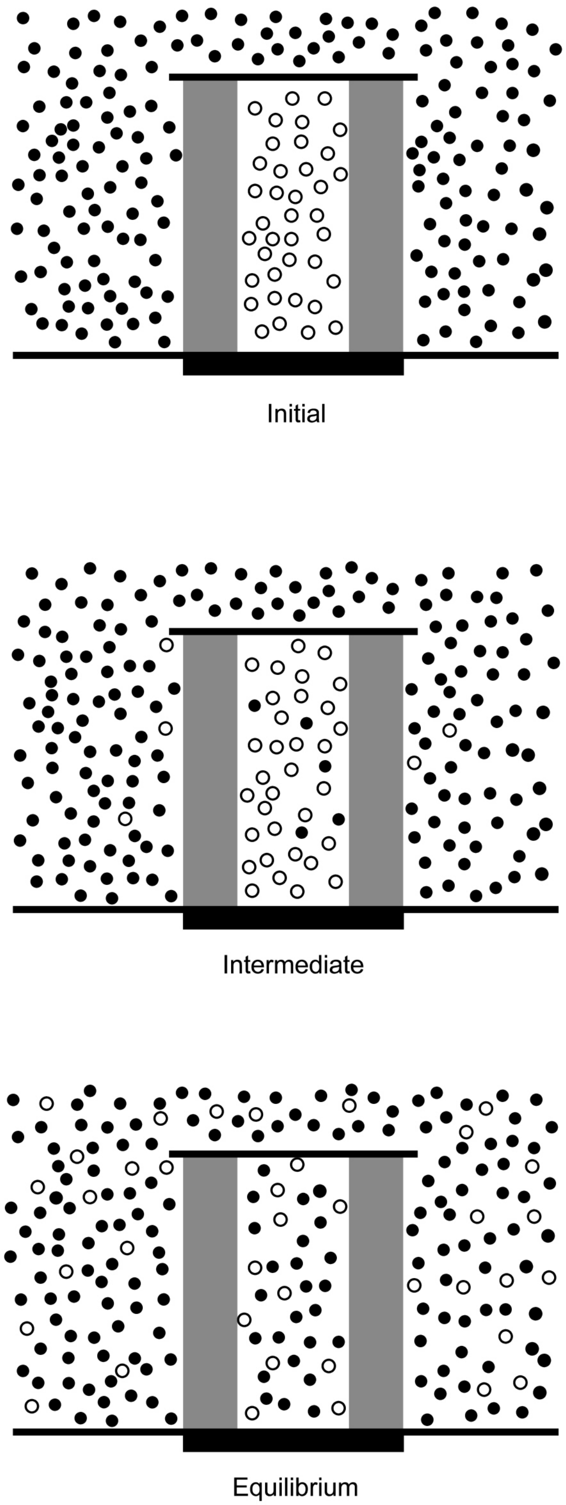

Figure 5. Diagram showing mixing stages during diffusion: initial (before mixing), intermediate (during mixing), and equilibrium (mixing complete).

Now let us suppose that our walls are permeable, with no vapor barrier, such that there is an exchange rate of 0.02 ACH. The latter corresponds to one complete indoor air and moisture change every 50 hours. This number is significant because mold colonies become established when susceptible materials have been damp for 24 to 48 hours.[33] Until that point of no return, if most of the moisture that collects within the wall cavity has had a chance to dry out through drainage and evaporation, sufficiently rapid diffusion may be enough to take care of the rest.

Timely reversal of the wetting process prevents significant mold growth. Otherwise there certainly will be permanent damage and the creation of an unhealthy living environment. Therefore breathability of wall materials *may* save the day, and thus indeed the home! (In addition to permeability, the forces of hygroscopicity and capillarity play an important role in drying out the structure. These mechanisms will be described at length in the following two sections of this chapter.) If you have trouble believing this point, consider the experience of George Swanson in Texas and Paula Baker-Laporte and Robert Laporte in New Mexico. These building biologists, architects and builders have looked and failed to find any water intrusion and mold problems in breathable buildings properly built with thick materials, sometimes with relatively small amounts of natural ventilation.

This is not to say that diffusion openness replaces correct ventilation. Nevertheless, according to Klaus Zahn, an architect and building biologist in Berlin, Germany, "We use capacity of diffusion as an important basis for biological building, but only 2% of the moisture 'walks' through the wall. Not much but enough to allow moisture that does enter the wall to find its way out and avoid mold and other damage."

In applying the principles of permeability and diffusion to wall systems, the main point to remember is that breathable walls defy commonly accepted logic in modern building practices. This is because they allow moisture to move into and then out of a wall *without* causing mold growth or structural damage. At the same time they provide the one thing you would not expect from a porous, low density wall structure, and that is excellent thermal performance. The latter is possible because unlike infiltration, diffusion is slow and therefore so is the rate of heat transfer. In fact, thick wall design using the right materials greatly enhances thermal performance. Finally, though not applicable to the topic of moisture transport, diffusion also plays a role in improving indoor air quality via the slow outgassing, dissemination and removal of volatile organic compounds (VOC's) and other toxic gases from a building. Here we should keep in mind that VOC's are much larger molecules than H_2O. Therefore diffusion is often slowed down or limited due to insufficient pore size or tortuosity of pores. Paints and coatings, often themselves sources of toxic VOCs, are also a consideration as they may further slow diffusion. We generally recommend wall finishes that allow breathability and hygroscopicity, as described in chapter 9. Nevertheless, it should be understood that VOC's are often unable to pass through moisture-permeable materials and must be removed by ventilation. Our preference is that they be eliminated by not applying them in the first place.

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[33] The following chapter explains the process of mold growth and why the first 24 hours is critical to prevent it.

6.4 Hygroscopic Adsorption/Desorption

Most of the experts we surveyed consider *hygroscopicity* to be the hallmark of breathability. But before we explain the nature of hygroscopicity and explore its practical application, it is helpful for the reader to understand a little about *adsorption*, the fundamental chemical process that is involved. Ad̲sorption should not to be confused with ab̲sorption, a physical mixing of different materials. (The following section will discuss one type of absorption.)

In adsorption a gas molecule such as H_2O (an *adsorbate*) forms a chemical bond with a solid surface. The adsorbate becomes an integral part of that solid, losing its own identity; indeed, there can be no "wetness" or propensity for mold formation no matter how much H_2O is adsorbed. Attraction between polarized atoms, such as hydrogen in water and oxygen on the solid material, form the basis of what is known as a hydrogen bond. This is the weakest form of chemical bonding and is therefore readily reversible.[34] (The reversal of adsorption, that is the breaking of the hydrogen bond and release of the water, is called *desorption*.)

As implied above, the chemical nature of material surfaces varies a lot from one material to another. For H_2O molecules to form hydrogen bonds, one needs suitable atomic structures on the surface to which they can bond. The most attractive structure for hydrogen bonding is what is known as a hydroxyl group (-OH), which is chemically very similar to H_2O. As illustrated in Figure 6, some surfaces, such as unfired clay, have many hydroxyl groups and are hydrophilic (water loving), whereas others, such as most plastics, have few -OH groups and are therefore hydrophobic (water repellant).

In order for a material to be considered *hygroscopic*, three conditions must be satisfied:

1. There must be a relatively high density of adsorption sites for H_2O, i.e. many suitable atomic structures per unit area of the material's surface.

2. The *internal* surface area of the material must be sufficiently large that the *total number* of adsorption events is large. (The external, visible surface area is usually negligible as it pertains to hygroscopicity!) Highly adsorptive, porous materials have internal surface areas on the order of 50 square meters per gram. This area corresponds to a football field for every pound of material! Moreover, for practical applications, one wants to use as large a mass (grams) of the material as possible, because the total surface area (square meters) increases accordingly.

[34] In the interests of clarity the discussion in this paragraph has been oversimplified. There are actually two forms of adsorption: chemisorption and physisorption. Chemisorption is what we describe in the text as "adsorption." It is often relatively weak, as in hydrogen bonding. Physisorption involves formation of multiple layers of molecules on a solid surface due to even weaker physical forces, without chemical bonding. The reader need not be concerned with physisorption as hygroscopicity involves a *chemical* form of adsorption.

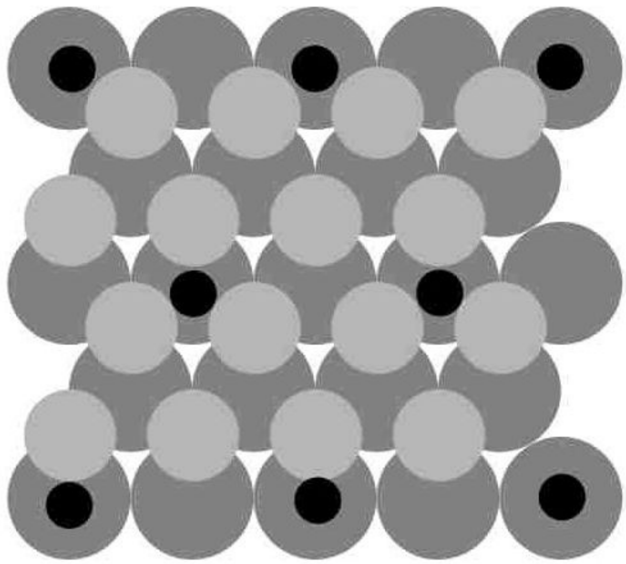

Figure 6. Two solid surfaces may have very different densities of surface bonding sites (●) suitable for adsorption. (a) and (b). *[This is only one of two such drawings to be included in the published edition. −Ed.]*

3. The material must be sufficiently permeable that water vapor can diffuse to the hydrogen bonding sites within its microstructure. There can be no adsorption if H_2O is not transported to the internal surfaces.

Hygroscopic materials are those having a high H_2O adsorption capacity, also known as the *equilibrium moisture content* (EMC) which is usually expressed in units of weight percent H_2O. Not surprisingly, the EMC is dependent upon the relative humidity (RH) of the surroundings, and to a lesser extent upon the temperature. A well-known example of this is the changing moisture content of wood with the RH. *Adsorption isotherms,* plots of EMC versus RH at constant temperature,[35] are commonly used to compare the hygroscopicity of different materials.

Some examples of adsorption isotherms are shown in Figure 7 which compares five different building materials. The shape of each isotherm is governed by the nature of the material's microstructure. However what is of practical importance is the *slope* of the curve over the range of relative humidity to which buildings are typically exposed. For this purpose one often considers the change in EMC values from 50% to 85% RH. (For monitoring water chemisorption, the data are useful only up to about 90 or 95% RH, at which point capillary condensation begins.) In the illustration, the sample labeled "Durisol"[36] (heavy black line), not

[35] Over the applicable range of environmental temperatures, the EMC for hygroscopic materials does not vary much from the value measured at 20 °C (68 °F).
[36] Durisol®, a low-density cement-bonded wood fiber block, is one of our recommended wall materials. See section 8.8.

only has by far the highest EMC over the entire 5 to 100% RH range, but it also has the greatest change in hygroscopicity from 50 to 85% RH, where moisture can become problematic. Concrete and lime plaster also show some hygroscopicity over the entire range, but much less so. Cement plaster exhibits a modest amount of moisture adsorption, but only at high relative humidity. Brick would definitely not be characterized as hygroscopic, as its curve hovers near the baseline until the RH reaches 90%.

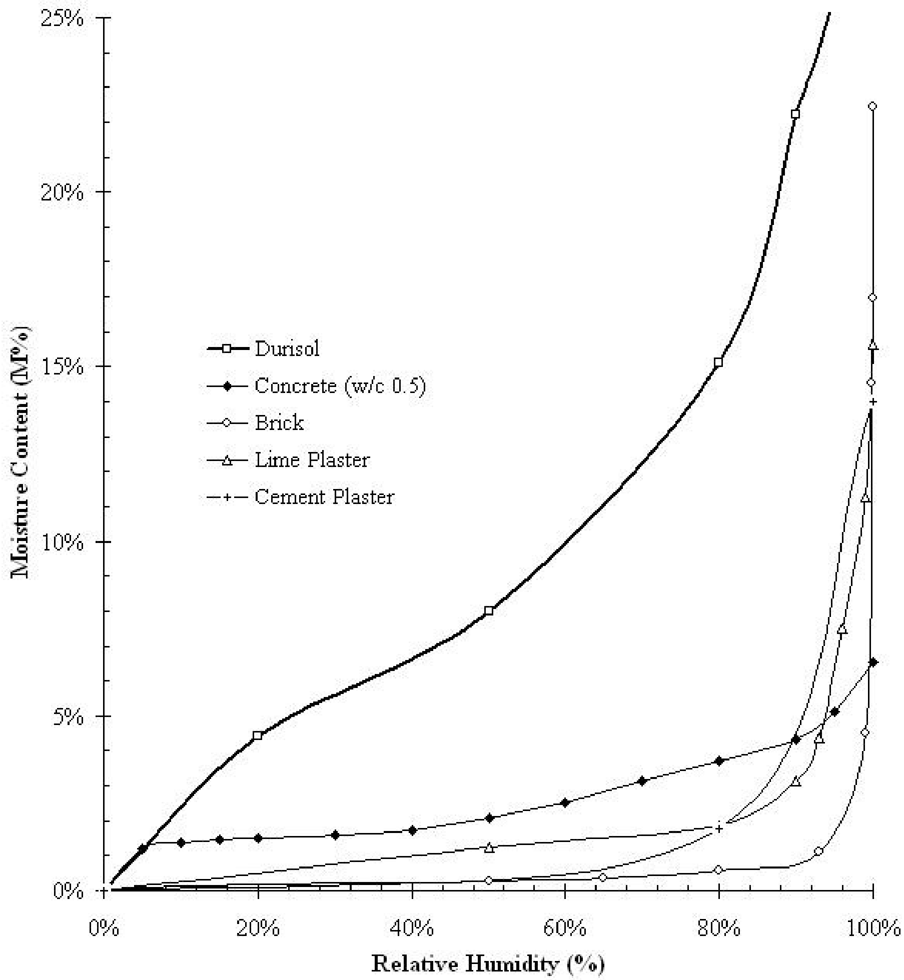

Figure 7. Water adsorption isotherms for several building materials[37]

[37] Figure 7, Figure 8, Figure 9 and Table 3 are used with permission of John Straube of the University of Waterloo, Ontario, Canada. They originally appeared in V. Acharya and J. F. Straube., "Indoor air quality, healthy buildings and breathing walls," in the *Proceedings of 1998 Excellence in Building Conference*, Washington D.C. The manuscript was posted at http://oikos.com/library/breathingwalls. A slightly enhanced version by J. F. Straube and J.P. deGraauw was published under the title "Indoor Air Quality and Hygroscopically Active Materials" in the *ASHRAE Transactions, volume 107, part 1* (2001).

Table 2. Hygroscopic Properties of a Variety of Building Materials

This table is derived from a number of sources, principally Neil May's previously-cited white paper entitled *Breathability: The Key to Building Performance.* Used with permission.[38]

Material Description	EMC at 50% RH (wt. %)	EMC at 85% RH (wt. %)	EMC Increase from 50 to 85% RH (wt. %)	Speed of hygroscopic adsorption
All plastic insulations All paints	0.	0.	0.	Not applicable
Fired clay brick	0.1	0.2	0.1	Medium
Gypsum plaster	0.4	1.0	0.6	Medium
Mineral wool insulation	1.3	2.3	1.0	Medium
Fiberglass insulation	0.	1.5	1.5	Medium?
Mortar, Portland-lime	4.6	6.5	1.9	?
Concrete	0.5, 1.9*	2.5, 2.6*	2.0, 0.7*	Slow
Stucco, Portland cement	3.0	5.8	2.8	Slow?
Aerated concrete	0.9, 1.1*	2.5, 5.0*	1.6, 3.9*	Medium
Unfired clay brick	4.	7.	3.	Very fast
Stucco, lime	4.0	7.4	3.4	Slow/medium?
Stucco, acrylic	1.6	5.4	3.8	?
Mortar, masonry cement	0.5	5.9	5.4	?
Spruce, transverse	9.	18.	9.	Slow
Spruce, end grain	9.	18.	9	Fast
Plywood	9., 5.1*	18., 16.3*	9., 11.2*	Very slow
Oriented strand board	4.8	15.7	10.9	Very slow?
Insulation: wood fiberboard, cellulose, flax, hemp or wool	8.	17.	9.	Fast
Low-density cement-bonded wood chip wall form (Durisol®)	8.	16.	8.	Fast?

*The two different values are derived from different samples and data sources.

[38] Other data were found in the Summary Report from Task 3 of the MEWS Project at the Institute for Research in Construction – Hygrothermal Properties of Several Building Materials, March 2002, available at http://irc.nrc-cnrc.gc.ca/pubs/rr/rr110/rr110.pdf.

At last it's time to apply our understanding of adsorption and hygroscopicity to the building envelope. The key point is that hygroscopic materials such as those recommended in this manual (see chapter 8) can regulate the relative humidity or moisture content of a room by storage and release of water. During periods of high relative humidity (RH), water vapor is adsorbed. During dryer intervals, water is desorbed, increasing the RH of the indoor air. Pure clay, for instance, has the capacity to adsorb roughly half of its weight in water vapor without getting wet,[39] a phenomenon that helps a wall material containing clay and/or plastered with clay to naturally regulate indoor relative humidity. This *buffering capacity*, as it is called by building scientists, minimizes spikes in humidity that would otherwise make the material susceptible to mold growth. These bursts in humidity are often the result of occupant activities such as cooking and showering. Over the longer term (days) weather is usually the major factor. Several European respondents to our questionnaire indicated that by extensive use of hygroscopic materials it is possible to regulate the relative humidity inside a building to 50 ± 5% throughout the year, at least under the most favorable circumstances, without the use of air conditioning.

Researchers John Straube of the University of Waterloo, Ontario, Canada and J.P. deGraauw and Vipul Acharya of Durisol Building Materials Ltd. of Hamilton, Ontario demonstrated the humidity buffering effect in a laboratory simulation comparing a conventional stud frame wall system having a vapor barrier (Figure 8) with an alternative wall system constructed using the highly hygroscopic Durisol® wall forms (Figure 9). In this experiment the interior of each test house was maintained at 21 ± 1 °C and 50 ± 5% RH throughout the winter heating season. The relative humidity inside each wall was monitored continuously during this interval – in the middle of the batt space or the middle of the Durisol® wall form as applicable.

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[39] In addition to having a very large water *vapor* adsorption capacity compared to other materials, many (though not all) clay minerals have the extraordinary ability when exposed to *liquid* water to swell to several times their initial (dry) volume and likewise dramatically increase their weight. Through various life experiences, the reader is probably more familiar with this other property of clays than they are with the vapor-phase process. These two processes should not be confused! The following example pertaining to clay plaster may make the distinction clearer. When one mixes the plaster and spreads it onto a wall or ceiling, interactions between the clay and *liquid* water do play a major role. However, once the coating has dried onto the wall, *vapor-phase* adsorption is responsible for the plaster's humidity-regulating properties.

The solid-liquid phase interactions responsible for swelling of clays involve a number of different mechanisms:

a. *capillary absorption* (see section 6.5) and percolation of liquid water through the pore structure of the solid
b. *chemisorption* (relatively strong adsorption, as per note 34) of a single layer of water molecules between the charged layers of the clay's silicate-based crystalline structure, a process called intercalation;
c. *physisorption* (relatively weak adsorption, as per note 34) of additional layers of water molecules;
d. further hydration, involving even weaker physical interactions at the interface between intercalated water and liquid water.

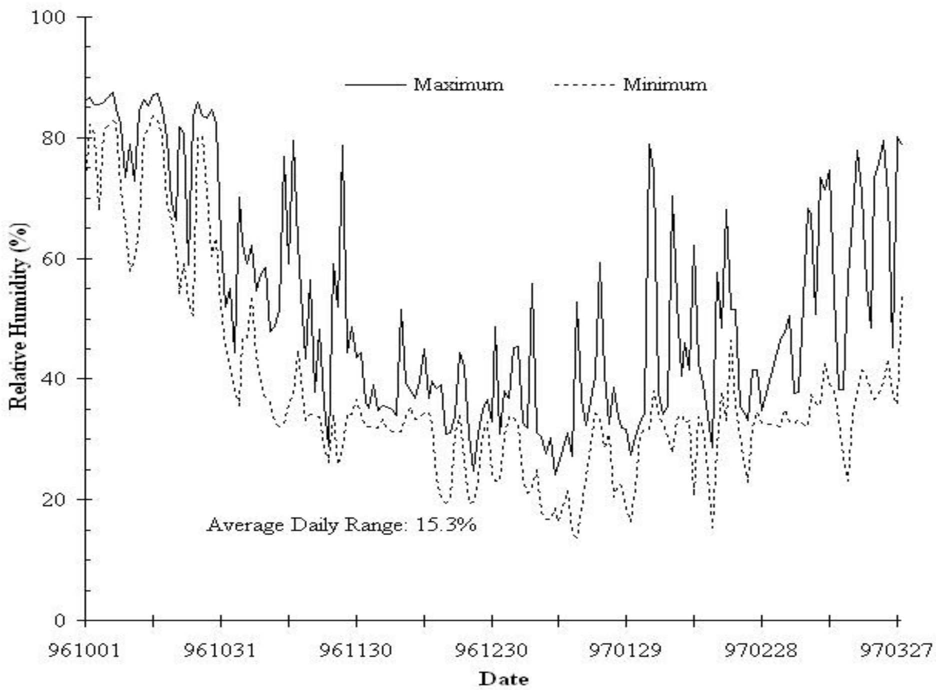

Figure 8. Variation of relative humidity inside a conventional wall system throughout the heating season.[37]

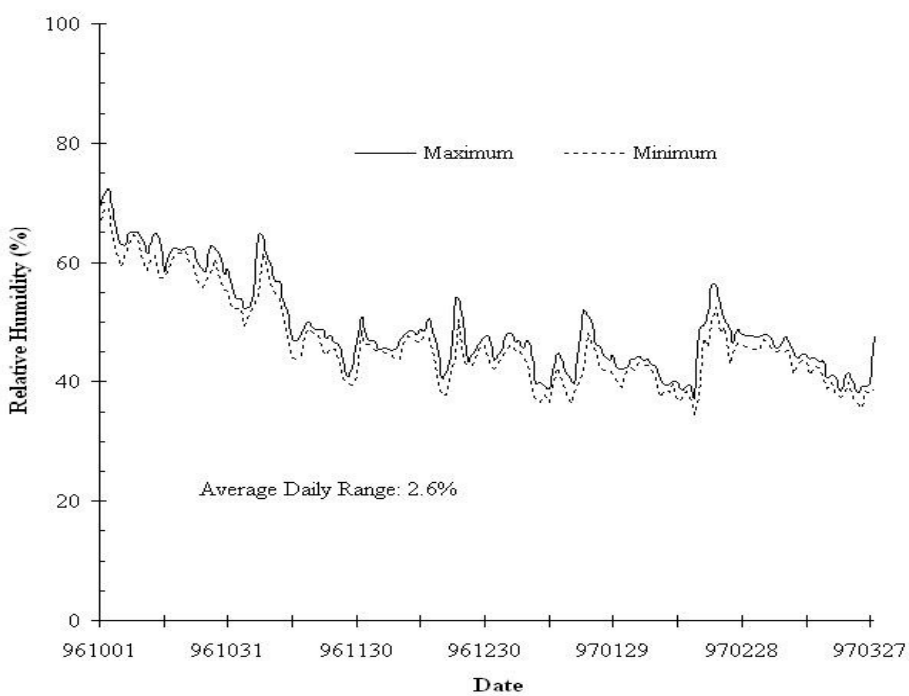

Figure 9. Variation of relative humidity inside an alternative wall system containing hygroscopic materials.[37]

Even though the Durisol® wall system was "designed to fail" by trapping in moisture with semi-impermeable extruded polystyrene (EXPS) insulation on the outside of the wall and using unpainted wall board on the inside, it clearly outperformed the conventional wall. One sees that over the entire winter the relative humidity inside the Durisol® wall varies much less over the course of an average day (2.6% variation) than that inside the conventional wall (15.3% variation). Moreover, there are days when the RH of the conventional wall spikes above 70%, a recipe for condensation and subsequent mold growth if drying cannot occur in time. During that winter the temperature dropped below -4 °F several times.

By contrast the Durisol® wall "never approached levels at which condensation might occur, even though there was no vapour retarder on the warm side of the wall, and despite a relatively impermeable outer sheathing … If the drywall had been painted, the Durisol plastered, or the EXPS sheathing replaced with a more vapour permeable material, the RH … would have been even lower."

For practical application of hygroscopic materials, the *speed* of adsorption or desorption is extremely important in addition to the EMC. The rate is governed primarily by how fast moisture diffuses through the material, as well as by the strength of the chemical bonding associated with the adsorption process. When moisture is rapidly vaporized by occupant activities such as showering and cooking, surface condensation and fungal growth can readily occur on cold walls if the introduced moisture is not quickly adsorbed. Straube and coworkers modeled the rate of hygroscopic adsorption for various wall systems using a sophisticated computer program that incorporated a range of material properties, including adsorption and diffusion parameters. These researchers' analysis in Table 3 (reproduced by permission[15]) ranked different materials according to their 24-hour moisture adsorption capacity in grams per square meter of surface, following a 50 percent increase in relative humidity (30-80% RH). Given a realistic magnitude of water introduced rapidly (from cooking or a shower) into a typically-sized room initially at a comfortable 50% RH, Straube and coworkers calculated the rating necessary for the walls to quickly adsorb the moisture influx and maintain the environment at 50% RH. Their conclusion: "This amount of moisture adsorption is easily and quickly (less than 1 hour) possible for walls rated over about 150 in … [the table]; it is not possible for walls rated less than about 50."

Straube and colleagues also commented that lime-based plasters are clearly superior to cement-based plasters, as the former respond within minutes to changes in relative humidity. We would add that clay plasters exhibit the same moisture regulating properties. By contrast the researchers pointed out that the excellent moisture storage capacity of log, straw bale or Durisol® is active over a longer timescale of several hours.

Table 3. Water vapor adsorbed in 24 hours by walls exposed to a 50% change in relative humidity.[37]

Rating (g/m^2)	Assembly Description
<10	Any system with vapor retarding paint (including oil based) or "high-quality" vinyl wall paper
40	Painted gypsum drywall on poly on wood frame, primer + 2 coats latex [We note that this is the wall system used in a typical modern home, excluding the insulation and siding.]
90	Concrete, unfinished
110	Extruded clay brick, unfinished
150	Softwood logs, unfinished
240	Straw bale wall with 1" lime plaster
250	Durisol Wall Form 20 System, finished with 12.5 mm lime plaster

Experiments by Minke[40] have demonstrated that in the first 24 hours only the most exposed one inch of a clay wall adsorbs a significant amount of water vapor. See Figure 10, which has been reproduced with permission of the author. The deeper layers begin adsorbing only after the first day. Until then the total water uptake does not depend on thickness over the range 2 to 8 centimeters (approximately 1 to 3 inches). This tells us that for short-term buffering of interior humidity, what materials are used for the external portions of the outer walls of the building does not matter and the interior finishing treatments play the biggest role. The computer modeling work of Straube and coworkers for different material thicknesses corroborates this conclusion.

Builder and materials supplier Neil May in the United Kingdom points out that over the course of several days, moisture diffusion through permeable outer walls enables stored moisture to be transported all the way through from the inside to the outside of the wall, in which case there is no *long-term* humidity buffering on the inside of the building. Neil writes:

> The ability of materials to take up moisture over time depends also on "Penetration Depth", which relates to the depth of the material which is actively working to buffer humidity. This buffering action will only take place in internal walls or ceilings which are not connected to the outside, or in external walls and ceilings where the outside is vapour impermeable. In external walls and soffits where the outside is sufficiently vapour permeable, then the partial vapour pressure differential between inside and outside will mean that most of the moisture which is stored is released to the outside rather than back inside. Penetration depth therefore relates to thickness, density, equilibrium moisture content and the position of the material in the building."

[40] Gernot Minke, *Building with Earth: Design and Technology of a Sustainable Architecture*, Birkhäuser - Publishers for Architecture (Basel·Berlin·Boston, 2006), p. 17.

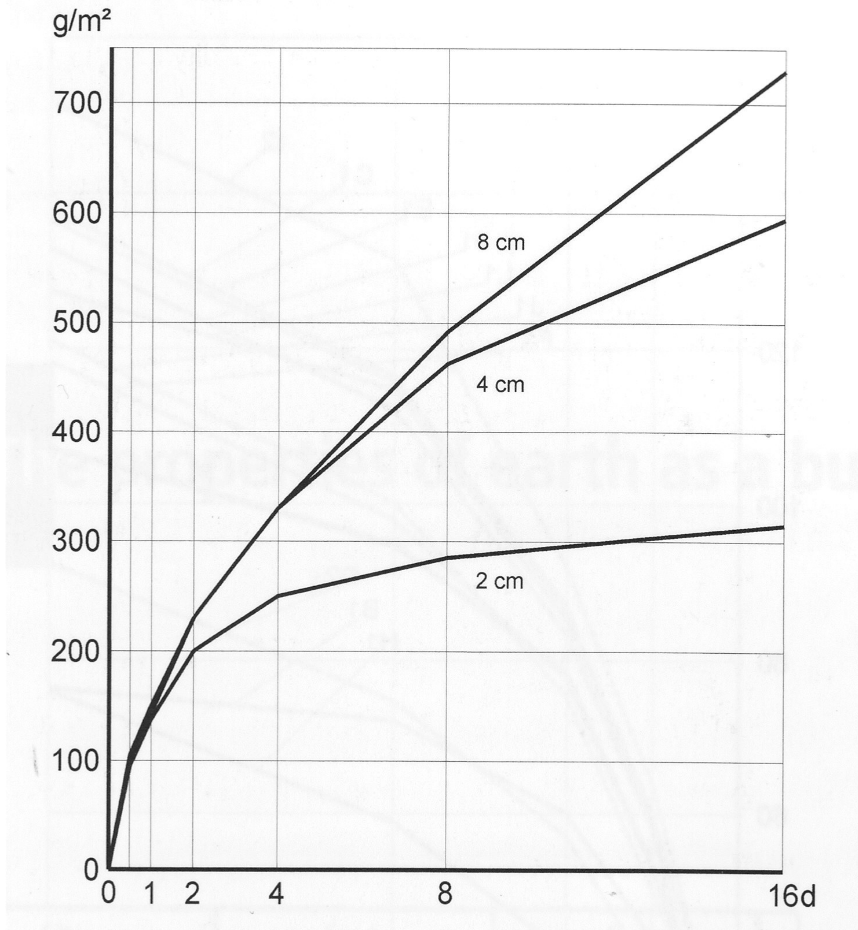

Figure 10. Effect of the thickness of loam layers on their rate of adsorption after a sudden rise of humidity from 50 to 80%. The moisture adsorption over a period of days is expressed in grams per square meter of wall surface. (Reproduced by permission.[40])

However, the use of hygroscopic outer wall materials such as those recommended in this manual *does* make a huge difference when it comes to interstitial moisture control; that is, controlling moisture within the wall material itself from such sources as rainwater leaks and condensation. If the wall is built with thick materials, then in the outer layers much of the water evaporates and is adsorbed harmlessly as water vapor. Subsequently desorption of water works in concert with diffusion, which was explained in the previous section, to remove water from the wall. This enables additional hygroscopic adsorption and further drying within the 24 to 48 hour danger period before mold becomes established.

Lastly, building scientist Carsten Rode of the Technical University of Denmark points out one more potential benefit of using hygroscopic materials to buffer indoor humidity variations: "if indoor humidity is a main reason for setting the requirements for (mechanical) ventilation, the peak ventilation requirement may be reduced because of the humidity interaction with the materials."

6.5 Capillary Absorption/Desorption[41]

The third mechanism of breathability is capillary action, often referred to as *capillarity* or "wicking." This physical process involves the flow of *liquid* water through pores within a material. The degree of capillarity is determined by the balance between forces of surface tension, adhesion, gravity and pressure. Capillary rise in a vertical column of material may be as large as tens of feet. For example, a green plant, even one as large as a tree, draws water up from its root system by capillary absorption. Similarly a building slab and foundation naturally tend to draw water up from the water table through wet soil. Of course capillary action may take place in every direction, not just up, as in the case of a sponge.

For significant movement of liquid water to occur, there are two basic preconditions:

1. The surface must be wettable, allowing the liquid to spread as it needs to before it can penetrate. Wettability may be profoundly affected by surface contamination or by the intentional use of coatings. For example, brick is normally (albeit not invariably) very capillary-open, but surface pretreatment with water-repellant silicone renders it closed.

2. The pore openings within the material must be *much* larger than needed for vapor transport, but not too large. Capillary action requires a diameter in the range of tens of microns to millimeters. Even the smallest of these orifices are visible under a magnifying glass, comparable to the diameter of a human hair. Thus voids, the extremely large openings between grains of a material, may be the primary pathway for capillary flow.[42]

Capillary absorption, the uptake of water by wetting, is typically measured in the laboratory by immersing a standard-sized cube of the test sample, with all but one the faces sealed. One then follows the weight gain from absorption of water over time. We wanted to present you with a handy chart that reliably compares the capillary properties of different building materials. However as noted in the Building Science Corporation's table of building material properties, "There is unfortunately … no ASTM standard for the water absorption coefficient, and few manufacturers in North America have measured or reported water absorption coefficients. When researching a building product, strongly encourage manufacturers to provide the water absorption coefficient."[43]

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[41] Again we thank Neil May of Natural Building Technologies in the UK, who taught us most of what we know about the role of capillary absorption in building science.

[42] The upper size limit for capillary action may be measured using a parallel plate method. Some results for building materials are available in Technical Series Report 97-107, Canada Mortgage and Housing Corporation, "Water Flow by Means of Capillary Action", as described at http://www.cmhc-schl.gc.ca/publications/en/rh-pr/tech/97107.htm.

[43] The authors found this table online at http://www.buildingscience.com/designsthatwork/buildingmaterials.htm.

Moreover, there is no well-established method for measuring capillary desorption, the wicking out of absorbed water; one can imagine blotting a material with a standard absorbent material. Whether one considers absorption or desorption, one is usually reduced to at best empirical, qualitative observations of capillary performance, if not educated guesses based on one's familiarity with the material. Nevertheless, keeping in mind all of the above limitations, we do present you with some values from the only two compilations of capillary absorption data we have found.[44] As explained below, there is not a straightforward rule indicating whether we want high or low capillarity. The reader will also note that some materials such as brick vary a lot, depending upon the manufacturing process. For capillary uptake to take place, obviously there must be liquid water present. In buildings rainwater penetration is the main source. To control moisture from being trapped within homogeneous materials there are four possible strategies:

1. Use materials that are capillary-open, allowing capillary absorption. Choose materials and a design such that the larger pores will readily empty by capillary desorption and be allowed to dry out by evaporation and diffusion. (Remember that gravity also must be countered.) A classic example is brick.

2. Use "free-draining" materials that have pores or voids exceeding the maximum pore size for capillary absorption. An example is low-density cement-bonded wood fiber block.

3. Select materials that are as closed to capillary action as feasible. (Note that this still permits some degree of vapor-phase moisture transport for permeable and hygroscopic materials.) An example is wood with only the transverse grain exposed, as in logs. When such a material is used alone and the joints are caulked, then there is no problem with water intrusion, assuming that they can withstand weathering from wind and exposure to ultraviolet light from the sun. (Of course a weather-resistant breathable protective coating on the exterior is needed for that purpose, with the interior left unfinished to allow curing of the wood over the first year, even if the wood was kiln dried.)

4. Seal up a capillary-open material by applying a suitable paint or coating. Some coatings in use today, such as an epoxy or rubberized coating, will block all three modes of transport by providing a virtually nonporous coating, which we do not recommend, primarily because when moisture does penetrate such a coating, it then cannot get out. However it is possible to block capillary flow of water into the substrate without necessarily closing all of the pores to vapor transport through the envelope.

[44] We thank Neil May of Natural Building Technologies for allowing us to adapt his unpublished table from his *Breathability: The Key to Building Performance* white paper that contains most of these data. Other data were found in the Summary Report from Task 3 of the MEWS Project at the Institute for Research in Construction – Hygrothermal Properties of Several Building Materials, March 2002, http://irc.nrc-cnrc.gc.ca/pubs/rr/rr110/rr110.pdf.

> One such approach is to apply a hydrophobic (water-repellant) coating, such as a glossy latex paint.[45] This forms a still relatively permeable network of polymeric strands, that prevents wetting of the surface as would be necessary for capillary action to occur.
>
> A second, much less common approach that we wholeheartedly endorse for waterproofing is to use a penetrating product that infiltrates the exposed pores of the material being treated, depositing finely-divided solids that strongly bond to and plug those pores and become an integral part of the substrate. The pores within the fine solids are sufficiently large for water vapor diffusion but too small for capillary uptake. The most time-honored example of such a product, developed in Germany in the 1870s by Adolf Wilhelm Keim, is inorganic mineral silicate dispersion paint, which utilizes potassium silicate as its binder. This and other nontoxic products that block capillary intrusion but preserve vapor permeability are discussed in later chapters.

Like hygroscopic adsorption, capillary absorption is reversible. But absorption and desorption may occur at significantly different rates. In some cases this difference plays a crucial role in the performance of building envelopes. For example, serious problems may result when materials get wet during construction and are covered up before they are allowed to dry, or if there is a construction defect such that intended moisture movement out of the building has been blocked by introduction of incompatible materials. What happens in this case is of particular concern when the material's capillarity is small, for when it gets wet it may be too slow to dry. Conversely, if capillarity is high, then a wet material will usually dry out rapidly. Therefore in building envelope applications we usually (but not always) favor the first two approaches, using breathable materials having high capillarity or ones that are free-draining. However Portland cement, which has a high degree of capillarity, is one material which we do *not* recommend. Large masses of concrete are exceedingly slow to dry out, for concrete starts out as a completely liquid-saturated material as a result of its formation by mixing in water. Even when cured the remaining water in the pores is desorbed only very slowly.

Before leaving this section, we should mention briefly what may be a familiar concept to the reader, the capillary break. The latter is simply a gap between discrete pieces of material that is larger than the maximum pore size required for capillary uptake. (These pieces may or may not be the same material.) This is an intentional design concept, not a materials concept, as it does not generally depend upon the properties of the materials themselves. (Here we exclude the cases of a crack within an otherwise homogeneous material or a free-draining composite, wherein there is essentially a capillary break within an inhomogeneous material.) Capillary breaks are useful for keeping water out of foundations and slabs as well as providing air spaces for drainage behind siding.

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[45] Oil-based painted surfaces are considerably less but still somewhat permeable, as are most relatively thin coatings.

Table 4. Capillary Absorption of a Variety of Building Materials

Material Description	Capillary Absorption ($kg/m^2 \cdot h^{0.5}$)
Low-density cement-bonded wood fiber block	0 (free draining)
Polymeric products	< 0.02
Paper-based products	0.03 to 0.06
Polyisocyanate insulation	0.w
Masonry paint	0.05$^?$
Mineral wool insulation	0.1$^?$
Plywood or oriented strand board	0.1$^?$ to 0.2
Expanded polystyrene insulation	0.2$^?$
Indoor emulsion paint	0.2$^?$
Spruce transverse	0.2
Lime stucco	0.3
Acrylic stucco	0.4
Portland cement stucco	0.7
Concrete	0.5 to 2
Wood fiber insulation	0.5 to 2
Lime or cement plaster	1$^?$x
Calcium silicate brick	1xx
Milk paint or pure lime wash	> 1xxx
Flax, hemp or wool insulation	1 to 2
Fiberglass insulation	2_
Spruce end grain	1.2
Clay plaster	2$^?$0
Unfired clay brick	2.0
Aerated concrete	2 to 8
Portland cement-lime mortar	4 to 5
Masonry cement mortar	0.7 to 5
Gypsum plaster	5$^?$0
Cellulose insulation	> 10xxxx
Fired clay brick	0.1 to 25

Neil May: “Again this table is taken from a variety of sources which may not be reliable or compatible. The idea however is to see how different materials can be in different ways.” Highly questionable data are denoted as such ($^?$).

6.6 Thermal Mass, “Out”sulation and Energy Efficiency

Now we turn to a phenomenon well known to some indigenous peoples for thousands of years. Thermal mass has been defined by researchers at the U.S. National Bureau of Standards in the following way: “The mass effect relates to the phenomenon in which heat transfer through the walls of a building is delayed by the high heat (retention) capacity of the wall mass…also referred to as ‘thermal capacitance’ or time lag - *the resistance of a material … over time, to* *allow a change in temperature to go from one side to the other.*"[46] This delay, which does not occur in traditional thin walled construction having relatively little mass, provides significant cost savings, comfort and better health for homeowners using massive, thick-wall construction.

High thermal mass or heat capacity (the latter being the preferred term of physicists) is one of the most important features distinguishing thick wall systems from conventional systems used today. Many builders shun thick wall materials because they are either unfamiliar with them or are under the mistaken impression that they do not insulate well because they have a lower R-value. They also don't like the added expense up front. When you step back from the mindset that today's high standard for R-value must be satisfied with a batt-filled or foam-filled wood frame wall, the fact that thick wall systems do indeed have a lower R-value can be understood in its proper perspective. That is, the lower value is deceptive because thick wall materials behave in a different way and insulate through different mechanics than wood frame walls. The reality is that thick wall materials insulate as well as wood frame walls in the field while having many advantages, not the least of which is the capacity to be naturally mold-resistant. Contrast that with modern walls that are often mold-filled because of efforts to tighten the house, which prevents the inevitable moisture intrusion from drying within the narrow 24 to 48 hour window before mold growth occurs (see chapter 7).

The steady-state R-value used to compare building materials are unfortunately measured in the laboratory at *constant* interior and exterior temperatures that generally do not exist in the real world. Nevertheless for conventional wood frame wall systems, which hold onto heat for no longer than about ten *minutes*, the actual thermal performance in the field correlates more or less with the R-value, at least insofar as we compare different materials used in wood-frame construction.[47]Therefore the steady-state R-value is useful and is firmly entrenched into the building code. On the other hand, all thermally massive wall systems currently available (see chapter 8) hold and radiate heat or cool for up to twelve *hours*, the actual duration depending on their thickness. Over this much longer time interval, the exterior wall temperature varies continuously and dramatically due to day-night temperature cycling and weather-related changes. Under those conditions, by ignoring the mass effect the steady-state model grossly underrates the performance of thick wall materials. Laboratory testing bears this out and is discussed below.

Before we elaborate on how thermal mass actually saves energy and present documentation of these effects, we want to dispel any concerns among our readers that *breathability* might be inconsistent with high thermal performance. Quite to the contrary, many breathable materials make excellent thermal insulators. For example, the matrix created by embedding cement-bonded wood chips in low-density fiber-cement wall forms makes use of the greatest of insulators, which is air. Each wall form contains on the order of forty to sixty

[46] The National Bureau of Standards researchers are quoted in a document found at various log home manufacturers' websites, for example http://www.northernloghome.com/rvalue.htm. This research will be discussed later.
[47] As a result of thermal bridging effects, laboratory testing indicates that conventional walls actually underperform their stated R-values.

volume percent air trapped between these mineral-encased chips, which make the wall form a fully insulating material throughout its composition. Additional insulation is provided by the insertion of rockwool pads into the cores. Other thermally massive materials, such as autoclaved aerated concrete, contain up to eighty volume percent air.

According to George, as cold winter air eventually migrates its way to the inside of any of these breathable, thick walls, 70-90% of the temperature gradient between outside air and indoor air disappears by the time the air reaches the inner surface, up to ten to twelve hours later. This happens because the inner one third of the wall has a temperature that is roughly the same as indoor air. As outdoor air slowly diffuses through this last (inner) one third of the wall, it gradually warms as it moves through. Therefore at least several hundredths of a room air exchange per hour is possible on a passive basis without significant thermal loss, provided you also use what we consider to be “breathable” interior and exterior finishes.

The key is the slowness of the migration of air and the fact that it mixes with pockets toward the inner part of the wall containing warmer air in winter and cooler air in summer. Compare this to faster cold air *infiltration* (not slow *diffusion*) entering a wood frame wall from outside in all the ways builders have come to loathe: between adjacent studs, around windows and electrical outlets, or through the space created in the cavity between the edge of an insulation batt and its adjacent stud. Now you see why a breathable, thick wall, with its ability to allow moisture to dry out and to slightly refresh and exchange indoor air with the outdoors, is not a hindrance to superior thermal performance.

Let us return to our consideration of the compound effects of thermal mass. Recall we were explaining that unlike conventional walls, which heat and cool within minutes of changes in the outside temperature but cannot hold onto that heat, thermally massive walls take many hours to heat up in the sun, or to cool off at night. Essentially they are passive solar collectors and designers should take advantage of this property. While many designers are familiar with the use of thermal mass by the Anasazi Native Americans in the ancient Southwest, there is much less awareness that modern building materials manufactured by reputable companies are now available that take advantage of these benefits and can be used in virtually all climates. The thermal lag characteristic inherent in these materials has several benefits that we will now describe.

A “flywheel effect” is created by the combination of temperature modulation and thermal lag in thick-wall construction. The wall temperature will differ hour to hour as the conditions within the inner one third of the wall shift in response to the hourly change in temperature on either side of the wall. This provides a self-regulating mechanism. For example, in a test home built with autoclaved aerated concrete in Amarillo, Texas, frequently exposed to outdoor temperature swings from 95 °F down to 60 °F within a 24-hour period, an actual *reversal* of the direction of heat transfer occurs within the wall during that interval, while indoor temperatures are easily maintained at a steady 75 °F.[48]

[48] “Thermal Performance for AAC Block: Residential Application,” a white paper prepared by Hebel for the Autoclaved Aerated Concrete Products Association (AACPA)

Under conditions of predominantly cooling, this heat flow reversal results in a substantially smaller heat gain by the overall structure because some of the heat initially absorbed by the outside wall surface *never* reaches the inside surface! Rather this portion of the heat is lost back to the outside later in the day or at night and that much less air conditioning is needed. A smaller air-conditioning system may do the job than otherwise might be needed, or indeed natural ventilation may suffice, and substantial upfront costs may be eliminated. Likewise commercial operators are able to cost-shift their cooling loads to evening and nighttime hours, as described below.

Experimentally quantifying the thermal mass effect in the field is hampered by the practical difficulties of matching all building materials by R-value and employing identical environmental operating protocols in wood-frame and massive constructions. Nevertheless, the effect was verified as far back as the late 1970s and early 1980s by researchers at the National Bureau of Standards at test homes in Bethesda, Maryland.[49] These tests showed that log or concrete masonry structures performed better than corresponding insulated wood-frame buildings in the intermediate heating season and the summer cooling season, although there was no appreciable difference during the winter heating season. The latter is explained by the fact that all buildings required comparable amounts of heating energy each hour to maintain their predetermined indoor temperatures. Some analysts have claimed that energy savings from thermal mass are limited to those situations where the outside temperature cycles daily above and below the indoor temperature setpoint. However George's experience incorporating external insulation ("out"sulation, see below) and the results of computer modeling that we present later in this section suggest otherwise.

Even if the diurnal temperature swing is not large enough to cause a reversal of heat flow direction, with thermally massive materials there is *always* a delay of many hours in heating or cooling of the building envelope in response to external temperature changes. This delay often saves money in the case of cooling loads, which are shifted to nighttime hours when the HVAC equipment needs to work less and electricity costs may be lower.[50] You then "compete against the average temperature of the day, rather than the peak temperature," according to the website of one of the manufacturers of autoclaved aerated concrete.[51] The need for smaller heating and cooling systems partially offsets the cost of incorporating thermal mass into the building. Incorporating thermal mass saves as much in

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and now available on one of their member's websites: http://www.e-crete.com/pdf/03-thermal_properties.pdf.

[49] The NBS studies and other pertinent research are described in a 2003 white paper published by the Log Homes Council of the National Association of Home Builders: "The Energy Performance of Log Homes – Documented Energy-efficiency and Thermal Mass Benefits," which can be found at http://www.loghomes.org/uploads/The%20 Energy%20Performance%20of%20Log%20Homes1.PDF. One of the original papers is reproduced on the web: D. M. Burch, W. E. Remmert, D. F. Krintz, and C. S. Barnes, "A Field Study of the Effect of Wall Mass on the Heating and Cooling Loads of Residential Buildings (aka Log Home Report)," *Oak Ridge National Laboratory Building Thermal Mass Seminar Proceedings*, Knoxville, TN, June 2-3, 1982, http://fire.nist.gov /bfrlpubs/build82/PDF/b82001.pdf. Reference 23 is a synopsis of the latter.

[50] Electric utility rates may be lower during off-peak usage intervals because of the reduced need to build peak electrical generation capacity.

[51] See http://www.safecrete.com/aac/benefits/energyeff.cfm.

operating expenses as another important component of a comprehensive energy saving strategy, high-efficiency windows, but often at lower initial cost. Finally, homeowners can withstand power outages much longer because mass-containing walls and floors hold heat for many hours.

Thermal comfort is another important benefit of using thermally massive materials. In field tests[48] of the thermal performance of a west-facing wall constructed of autoclaved aerated concrete block, painted black on the outside to maximize solar gain, temperatures measured on the inside of the wall were easily maintained *without air conditioning* in a steady range at 68 ± 2 ˚F during a 24-hour period while the outdoor wall surface (not air) temperature varied by as much as 126 ˚F.

These results further illustrate the comfortable and healthy climate that is provided by breathable, thermally massive construction. We have already seen that when these materials are also hygroscopic, the indoor relative humidity may be kept within comfortable limits. Moreover the absence of thermal bridging due to the continuity of interconnected wall forms or wood log creates uniform wall temperatures, avoiding the hot or cold spots characteristic of standard wood-frame construction. Two-dimensional, finite-element, steady-state modeling of walls constructed from low-density fiber-cement forms predicts temperatures uniform to within 0.2 ˚F, compared to a variation of 2.5 ˚F with batt-insulated stud frame walls. Under heating conditions the lowest wall temperature is 2.3 ˚F warmer than that for a standard wall.[52]

Turning to the construction with low-density fiber-cement wall forms, ideal thermal performance is gained by isolating the mass toward the inside of the wall. This is accomplished by positioning mineral wool inserts toward the outside of a hollow core filled with concrete and rebar. The internal concrete mass within the hollow is thereby insulated from the outside. The cement-bonded wood fiber jacket itself supplements the insulating capacity of the mineral wool insert.

George nicknames this "out"sulation because the insulation is placed towards the outer half of the wall. "Out"sulation prevents any heat stored in the thermal mass of the walls from being conducted rapidly to the outside. The entire wall system therefore has "thermal mass with 'out'sulation." In parts of Europe, it is popular to use wood fiber board panels a few inches thick (see section 8.12) as "out"sulation, but unfortunately these products are unavailable in North America. Low-density fiber-cement wall forms can be considered the original insulating concrete forming, or ICF, system. Modern ICFs are comprised of stay-in-place rigid foam forms with concrete poured into the core. While they are a step in the right direction, their design does not allow them to fully provide the benefits of thermally isolating the massive concrete core to the inside of the wall, because the inner foam layer isolates the concrete-filled core from the conditioned space indoors. This minimizes transfer of heat or cool between the room and the mass within the wall, largely defeating the purpose of having the mass. A wall made of low-density fiber-cement, on the other hand, allows full heat and cool transfer

[52] See "The Thermal Performance of the Durisol Wall Form System," Durisol Corp., revision 1/4/2006; http://www.durisolbuild.com/Webdocs/Durisolthermalperformance.pdf.

between the room and the thermal mass of the wall along its entire length and height.

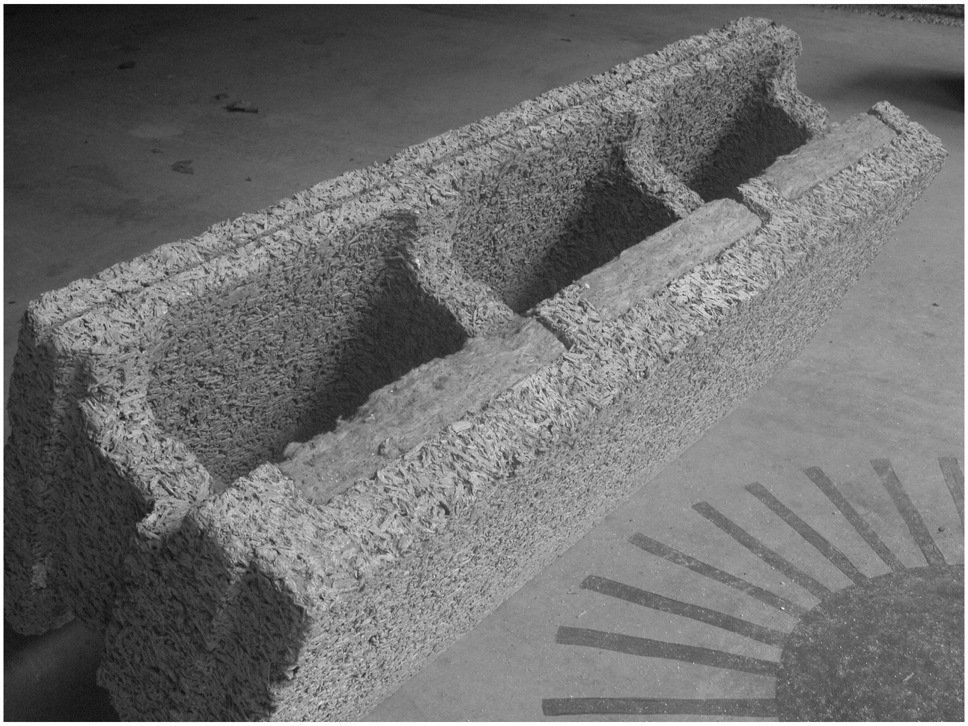

Figure 11. Mineral wool inserts provide "out"sulation in cement-bonded wood fiber wall forms.

George's subjective field observations of the superior performance of walls with "out"sulation have been corroborated by computational modeling of the dynamic thermal behavior of massive envelopes, conducted at the Oak Ridge National Laboratory's Building Technologies Center.[53] For each of ten different climates, Kosny and colleagues examined four different wall configurations over a range of R-values: internal mass with "out"sulation ("Intmass"); exterior mass with insulation ("Extmass"); mass surrounded on both sides with insulation ("ICI," or insulation-concrete-insulation, like a conventional ICF system); and finally, insulation surrounded by mass ("CIC," or concrete-insulation-concrete). Intmass and CIC configurations clearly outperformed the other two in both heating climates and cooling climates. Intmass was only slightly better than CIC and Extmass was the worst, leading the researchers to conclude in their 2001 report that what's most important is that the mass make good thermal contact with the interior of the building.

[53] J. Kosny, T. W. Petrie, D. Gawin, P. W. Childs, A. O. Desjarlais, and J. E. Christian, "Thermal Mass – Energy Savings Potential in Residential Buildings," Building Technologies Center, Oak Ridge National Laboratory, Oak Ridge, TN, August 2001. See http://www.ornl.gov/sci/roofs+walls/research/detailed_papers/thermal/index.html.

For every set of input including wall material configuration,[54] building design and local climate data, the Oak Ridge researchers' three-dimensional finite-element model produces a factor called the Dynamic Benefit for Massive Systems (DBMS). Multiplying the DBMS times the steady-state R-value gives what is essentially an *effective* or *mass-enhanced* R-value. Kosny and coworkers reported for their ICI and IntMass configurations, that

> The most favorable climates for both wall systems were in Phoenix and Miami and the worst locations were Minneapolis and Chicago. However, even for the worst locations, the DBMS values were close to 1.5. The range of DBMS values for walls with exterior foam insulation (DBMS - from 1.4 to 2.8) is much wider than a very flat chart of DBMS values for the ICF wall system (oscillating around 1.5). This is caused by different distributions of mass and thermal insulation in these walls, generating significant differences in DBMS values for the same climate.

A massive wall rated at R-17 with a DBMS of 1.5 would therefore have the same annual energy consumption as wood-frame construction with an R-value of 25. Increasing the DBMS to 2.8 would increase the mass-enhanced R-value to R-48. But note that the DBMS and effective R-value characterize the thermal mass benefit for only the chosen wall material configuration, climate, building size, building configuration and orientation. Unlike the steady-state R-value, these parameters *cannot* be generalized for a given material. They predict the properties of a system under certain operating and climatic conditions, but they are also helpful in convincing builders and homeowners that thick wall materials can be trusted to heat and cool as well or better than conventional wood frame walls.[55]

How does the dramatically enhanced thermal performance of thermally massive walls translate to whole-building energy efficiency? For a 1540-square-foot ranch house, the model predicts that replacing wood-framed walls with massive walls in the most efficient Intmass configuration could save up to 8% in a primarily heating climate like Minneapolis, and 18% in a primarily cooling climate like Bakersfield, California. One would expect higher than 8% savings in other regions of the country with more moderate heating requirements.

These results have profound implications in today's world of climate change and excessive energy consumption. Moving away from thin wall envelopes with virtually no thermal mass and towards construction of thick wall envelopes makes sense from a global climate perspective. We join the authors of three different industry white papers[48,49,52] as well as Oak Ridge National Laboratories in urging building code officials to take the effects of thermal mass into account when they set thermal standards. That would pave the way for the acceptance of thick wall materials as alternatives to conventional wood-frame construction. For many years the researchers at Oak Ridge have been developing "a rating and

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[54] The "wall material configuration" describes one or more materials of specified thicknesses and geometries

[55] Kosny and coworkers emphasize that DBMS values "should be used only as an answer to the question: 'What wall R-value should a house with wood frame walls have to obtain the same space heating and cooling energy consumption as a similar house containing massive walls?'"

labeling procedure that will enable consumers to determine R-values for whole walls rather than to focus on the misleading 'center-of-cavity' R-values." An interactive calculator that simplifies the required computation can now be downloaded,[56] and a library containing whole-wall R-values and other parameters is being created "to enable us to establish an acceptable consumer product label for the entire opaque wall area."[57]

The following section discusses how thermal mass imparts another desirable property to a building envelope, the intrinsic ability to provide healthy, steady radiant heat or cool for occupants.

6.7 Radiant Heat Transfer

A direct benefit of having a thermally massive building envelope, especially one well exposed to the sun, is that the envelope itself supplies a small portion of the heating or cooling budget at no operating cost using the healthiest mode, namely infrared *radiation* and absorption. Moreover, there is a phase delay, such that heating or cooling occurs at the time when it is most needed. This section will explain the heat transfer dynamics and why thermal radiation/absorption is optimal for comfort and health.

Radiative or "radiant" heat transfer is only one of the three possible mechanisms for heat flow into or out of the building envelope. Other possible modes of heat transfer are *conduction* and *convection*. For purposes of comparison, before exploring the more complex nature of *radiation*, let us examine these other mechanisms with the help of building-related examples.

Thermal *conduction* is simply the spontaneous transfer of heat directly between an object and the surrounding medium, or between two objects or two fluids.[58] As with all forms of heat transfer, the cooler object or fluid becomes warmer, and vice versa, leading to a smaller temperature difference than at the outset. The rate of heat transfer is proportional to the temperature gradient multiplied by the thermal conductivities of the materials or fluids. A classic example of conduction is the phenomenon of "thermal bridging" in buildings, wherein heat escapes in cold weather through a wood stud from the interior to the outside air. Actually much of the heat loss through the surrounding insulation is also via conduction, but the latter occurs at a much slower rate than conduction through the wood framework. If that example is too complicated, consider the simpler case of putting your hand on a hot stove burner—it hurts!

In thermal *convection*, the fluid itself (a liquid or gas) moves from one location to another, accompanied by its thermal energy.[59] For example, wind-blown cold air

[56] See http://www.ornl.gov/sci/roofs+walls/AWT/InteractiveCalculators/index.htm.
[57] See http://www.ornl.gov/sci/roofs+walls/AWT/AdvancedWallSystems/research.htm.
[58] On a more fundamental level, it is kinetic energy that is transferred during collisions between molecules at the surface of the respective objects or fluids. The absolute temperature of an ideal gas is proportional to the average kinetic energy of its molecules.
[59] There are actually two different types of convection. In *natural* convection there is spontaneous molecular movement across a preexisting temperature or concentration

infiltrates a wall through gaps in the insulation such as around electrical outlets, transferring coolness to the living space. (Almost simultaneously, warm air escapes the building somewhere else due to the pressure gradient.) Another example is a forced-air (HVAC) heating system, wherein the occupant's skin is ultimately heated by contact with warm air transported across the combustion unit or heater.[60] In chapter 14 you will learn why we say convective heating is a poor choice compared to radiant heating.

That brings us to our preferred mode, thermal *radiation*. Here the warmer material or fluid emits a generally safe spectrum of radiation that is absorbed in turn by the cooler medium. The average and minimum wavelengths of this radiation are inversely proportional to the surface temperature of the emitting object. Thus the warmer the surface temperature of the emitter, the emission spectrum is shifted to shorter wavelengths. Typical wavelengths are 0.8 to 100 micrometers,[61] corresponding to the infrared range of the spectrum.[62]

An infrared beam feels warm to the touch because the energy is absorbed directly into the body's molecular vibrations, especially those of water within and outside of our cells, and the vibrations generate heat. The ultimate experience of radiative heat transfer takes place when one sits in the bright sun, feeling toasty warm, even if the air temperature is well below freezing and there is a light breeze!

On a practical level, perhaps the most important difference between conductive or convective versus infrared radiative heating is that the first two are very superficial, initially reaching only the extreme outer surface of the skin, whereas the latter penetrates directly into the epidermis or below. For that reason, radiative heat is perceived to be more comfortable by homeowners. Sunlight, emitted from an extremely hot (nearly 10,000 °F) surface, includes the shortest and therefore most energetic wavelengths in the infrared region of the spectrum, sometimes termed the IR-A. These wavelengths of 0.8 to 1.4 micrometers penetrate the deepest of all infrared wavelengths, reaching several millimeters into the tissue according to a statement recently released by the International Commission on Non-Ionizing Radiation Protection (ICNIRP).[63] Therefore the sun's infrared radiation easily reaches all of the skin's nerve cells within the dermis (which is beneath the epidermis) that are part of the body's thermoregulatory system and makes us feel warm. Additionally, at least some bone surfaces, having significant thermal mass and laying fairly close to the surface of the skin, are also warmed directly by solar radiation. The effect is long lasting because a person's bone mass stores heat (or cold) for several hours. That is why we feel warm for a long time after sitting in the sun.

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gradient. In *forced* convection an external source such as a fan or pump is responsible for the movement.

[60] To make things complicated, in this case the human body is actually heated by thermal conduction from the surrounding air in motion.

[61] For reference, the diameter of a human hair ranges from 17 to 180 micrometers, according to one Internet source: http://hypertextbook.com/facts/1999/BrianLey.shtml.

[62] However, radiant energy transfer also occurs with visible light. Just think of the sun or a red-hot poker; they emit broad spectra including both visible and infrared.

[63] The International Commission on Non-Ionizing Radiation Protection (ICNIRP) "Statement on Far Infrared Radiation Exposure," published in *Health Physics*, vol. 91, no. 6, pp. 630-645, December 2006, available at http://www.icnirp.de/documents/infrared.pdf.

However, even the most sun-saturated, thermally massive building envelope at its peak solar gain never reaches temperatures greater than about 150 °F[64] and temperatures of the inner surface of the envelope during the heating season are well below 100 °F under all circumstances. Recall that the minimum and average wavelengths of the emitted radiation from a hot object are inversely proportional to its surface temperature. Therefore the shortest and most penetrating wavelengths of the secondary radiation, the radiation emitted from the building envelope into the interior space, are longer than those of the IR-A rays coming from the sun. The radiation from the building envelope falls primarily into a different region of the infrared spectrum, the IR-C that encompasses significantly longer wavelengths of 3 to 1000 micrometers. A small amount of the secondary radiation also falls into the IR-B region, which extends from 1.4 to 3 micrometers. Both of these penetrate less deeply into our skin than do shorter IR-A wavelengths that are available to heat us directly only when the sun's rays strike us.[65] Otherwise we benefit only from the indirect effects of the sun striking the outside of the building envelope.

A paragraph in the previously cited ICNIRP statement[63] explains the very different physiological effects resulting from absorption of this longer-wavelength infrared radiation:

> It is critically important to distinguish IR-C (and IR-B) from IR-A, where the infrared penetrates well into the dermis and even deeper into the sub-cutis. The dermis is approximately 1 mm thick and contains most of the nerve endings, whereas the epidermis [laying above it] is at least 100 μm [micrometers] thick[66] [at most body areas only one tenth the depth of the dermis] and has no blood vessels. IR-B is absorbed in the epidermis and dermis, but is not absorbed as deeply as is IR-A radiation. IR-C is totally absorbed in the stratum corneum [the outermost layer of epidermis, consisting of 15 layers or more of mainly dead cells] and superficial epidermis. Thus, *deep heating by IR-C is only achieved by heat transfer, i.e., heat conduction in the tissue and by blood flow* [emphasis added]…

Contrary to the claims of some firms marketing far-infrared saunas that their rays are deeply penetrating, the scientific research we've found indicates that for the most part these longer wavelengths only penetrate into the human body about a

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[64] For the sake of this argument we choose 150 °F because that is about the hottest that an unvented attic ever gets.

[65] It should be understood that the sun also provides a full spectrum of IR-B and IR-C wavelengths. However the shorter IR-A wavelengths have the greatest physiological effect due to their greater penetration depth, so we focus on them.

[66] Actually, our brief examination of the dermatological literature indicates that "at least 100 μm" (one tenth of a millimeter) is a slight overestimate. For example, in *Acta Dermato-Venereologica*, volume 83, number 6, November 2003, pp. 410-413, Jane Sandby-Møller and coworkers report total epidermal thicknesses of 75, 81 and 97 micrometers for the dorsal forearm, shoulder and buttocks, respectively. Elsewhere we learned that in areas of the body such as fingertips, where a lot of protection or grip is required, the epidermis may be thicker than 500 micrometers (0.5 mm).

tenth of a millimeter due to strong optical absorption by water, reaching the epidermal layers only, and not the deeper dermis.[67]

Thus radiation from the building envelope or for that matter from any low-temperature radiant heating system[68] besides sunlight coming directly through a window is hardly capable of *directly* heating our living tissues. Then why do homeowners feel so comfortably warm in winter living in thick wall homes?

As stated above by the committee of health physicists who wrote the ICNIRP document, any heating of the deeper, living tissue by IR-C radiation is an *indirect* effect, stemming from conductive heat transfer and blood flow that follows radiant heating of the outer epidermis. However there is another possible explanation for the thermal comfort resulting from low-temperature radiant heat. The minimal penetration of IR-C rays may be just deep enough to stimulate the Bulbs of Krause, nerve cells that are sensitive to heat loss, located near sweat glands in the very outer portion of the dermis. If not, the small IR-B component of the radiation could probably accomplish this. The Bulbs of Krause as well as the Organs of Ruffini, which are sensitive to heat gain much deeper in the skin, are central to our thermal regulation.[69] Stimulation of these nerve endings could explain why, independent of any heating of tissues that might occur, infrared radiant heat produces a very different, and more comfortable, physiological effect than that resulting from the totally superficial heating by convection or conduction.

Our sense of thermal comfort, the primary input variable for our thermal regulatory system, is determined by more than just the ambient air temperature, which is the sole means by which occupants are heated within a wood frame building served by a forced air system. Basically we are comfortable when we are able to lose the same amount of heat as we generate, without having to sweat or shiver. The temperatures of the surfaces surrounding us (walls, floor, ceiling, windows, etc.) are as important as the air temperature, for radiation accounts for at least *half* of the body's total heat exchange. Too much heat or cold on one side is perceived as discomfort. (Studies have indicated that walls that are too cold or ceilings that are too hot cause people the greatest degree of discomfort.[70]) A thermally massive wall system results in more uniform surface temperatures—or to use a more technical term, smaller radiant temperature asymmetry. Our bodies are kept warmer in winter and cooler in summer as a result, and we perceive our home and office to be more comfortable.

Improving the radiant heat transfer with thick-wall construction also allows us to save energy by heating the building to a lower air temperature. As explained by

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[67] To supplement the assertions found in the ICNIRP publication, we found an infrared absorption depth profile for human skin in a European brochure for sauna lamps: http://www.lighting.philips.com/gl_en/global_sites/application/sauna_heating/pdf/infrared-cabin635_22601.pdf. This graphic suggests slightly deeper penetration (to 0.1 mm) of long wavelengths than that stated by the international commission.

[68] Here we exclude higher temperature radiant heat sources such as wood-burning stoves.

[69] A tutorial on the body's thermoregulatory system is provided at http://healthyheating.com/Thermal_Comfort_Working_Copy/HH_physiology_3_skin_sensors.htm.

[70] PowerPoint presentation of INNOVA Thermal Comfort Solutions, last accessed in November 2007 at a different URL, now listed on http://www.lumasense.dk/Presentations.61.0.html but no link available.

architect and passive solar expert Edward Mazria in what is now a classic book,[71] by considering the relative importance of the various operative heat transport mechanisms,

> It is possible to establish a relationship between the average temperature of all surrounding surfaces or mean radiant temperature (mrt) and space air temperature. A 1°F increase in mrt is assumed to have a 40% greater effect on body heat loss than a one degree change in air temperature. Or, for the same feeling of comfort (70 °F), for each 1°F increase in mrt the space air temperature can be reduced 1.4°F….Notice that a mrt of 75 °F and air temperature of 63 °F will produce the same feeling of comfort as a 70 °F mrt and 70 °F air temperature.

Moreover, Mazria goes on to say that

> Within their comfort range, most people will accept the statement that the lower the air temperature in a space, the greater the sensation of comfort and health. Many people feel cooler air is more invigorating, fresher and less stuffy, and that their ability to work and think increases in a space where they are warm but the air temperature is lower than 70 °F.

Needless to say this has important implications for our efforts to cut the use of fossil fuels on a global scale.

In chapter 14 we will resume the present discussion of radiant heat transfer. There we will consider the benefits of *interior* radiant heating and cooling to complement that provided by the building envelope.

6.8 Structural Integrity

Structural integrity and durability under all applicable environmental conditions are obvious but nevertheless critical requirements. Materials should be dimensionally stable and resistant to rotting, corrosion, cracking, fatigue, wind and fire. All materials and systems presented in this manual possess such properties. They may be more expensive than conventional products, but they pay for themselves over time. As more homeowners and builders choose these options, with the explosion of interest in green building, economies of scale will bring prices down and availability up. Materials that breathe and handle water well pay for themselves in both performance and durability. Buildings in Europe covered with mineral silicate paint still have a pristine finish after 125 years. Homes in Germany built with post-and-beam mineral-fiber construction still stand today, centuries later. Cathedrals stuccoed with magnesium oxide have no cracking in their facade after many centuries.

Relatively few of the building materials covered in this manual offer in and of themselves the full range of desired properties affording breathability, thermal mass and structural integrity. In some cases our preferred materials do require

[71] Edward Mazria, *The Passive Solar Energy Book*, Rodale Press, Emmaus, PA, 1979, pp. 64-65.

some degree of structural reinforcement such as with rebar and cement. We discuss these options in detail in chapter 8.

The methods we recommend for ensuring structural integrity can themselves contribute to healthy building envelope design. One example is the application of a mixture of magnesia, clay and borate sprayed onto wood studs and sill plates to impart fire and rot resistance to a conventional wood framework. The protocol is completed by using magnesia-based sheathing and drywall and cotton batt insulation. This treatment complements the mechanical strength of the wood and provides an affordable, fully breathable wall that handles moisture well, enhancing the degree to which the envelope possesses the "ideal" qualities detailed elsewhere in this chapter. The use of forced grown lumber, with its artificially large cells, especially benefits from this process, which is detailed in section 10.4.

6.9 Protection from Incoming Radio Frequencies (RF)

One of Anton Schneider's basic principles of Building Biology® (see chapter 5) states that we should change our exposure to the natural balance of background radiation as little as possible. The latter includes naturally-occurring radio and microwave frequencies (RF), which are emitted at low fluxes from the earth and the cosmos, in addition to other emissions having much higher or lower frequencies. (X-rays and gamma-rays emanate from natural radioactive materials. Another example is the earth's oscillating magnetic field, which resonates at a frequency remarkably in tune with our alpha brainwaves.) The thought behind this principle is that, if man evolved in a certain environment, then that environment may be what's healthiest for us. A few researchers have begun to explore this relationship.

On the other hand, our desire to be fully immersed in the natural environment is balanced and often superseded by another of the 25 principles cautions that we should *avoid* unnecessary exposure to *technological* electromagnetic and radio frequency radiation. The good news is that building biologists have developed protocols to minimize our exposure to man-made electromagnetic radiation, particularly from the electrical system powering our own buildings. (Unfortunately our electro-biological protocols to minimize the health effects from a building's own electrical system are not covered in this volume, due to our focus on the building envelope. However, for those who would like to learn how to guide their electrical contractor in how to implement these protocols, these techniques are taught by the International Institute for Bau-Biology® and Ecology. You can also contact a practicing building biologist to consult with your electrical contractor. For more information visit www.buildingbiology.net.

We also recommend ways to avoid exposure to sources of wireless communications through the use of telephones and computers within the home that have hardwired connections. Options include corded telephones and the installation of CAT-5 and Ethernet cables for high-speed Internet. (You will also need to find out how to disable the wireless feature of your Internet router, using your web browser to access the control panel of the router. Your Internet service provider or the manufacturer of your router can assist you with this.)

Unfortunately it is more difficult to avoid exposure to airborne radio frequencies or microwave radiation coming into your home from outside the building envelope. The intrusion of these frequencies into buildings, particularly in the urban environment, has become endemic over the last ten years, and the situation is rapidly getting worse. Increasingly we must contend with the likes of radio and television broadcast towers, cell phone and pager antennas, wireless Internet (Wi-Fi) routers in neighbor's homes, and now, city-wide Wi-Fi broadcast systems mounted on light poles. With the coming of such higher-intensity wireless telecommunication technologies as "Wi-Fi Max" and "Broadband over Powerlines" (BOPL), both of which promise to emit even stronger signals from outside (as well as inside) the home, it is wise to protect oneself by building an envelope that is relatively opaque to RF waves, as discussed below.

Recently published research in the peer-reviewed August 2007 report of the BioInitiative Working Group, a panel of internationally recognized scientists, physicians and public health experts from the United States, Europe and Asia, bears this out. News reports in the European and world press document these findings, which have led the EU's European Environmental Agency and the German government to now caution their citizens to reduce exposure to wireless Internet routers, cell phones and cell towers.[72,73,74] Furthermore, schools are removing Wi-Fi networks in England[75] and the Austrian province of Salzburg is considering a ban on Wi-Fi networks in schools.[76] Concern is rising about the human exposure to wireless technologies worldwide, and our profession recommends that people take all steps possible to limit their exposure, whether they are symptomatic or not.

Even people living in rural areas are not free from the effects of electrosmog, because Internet service providers are now installing wireless Internet (Wi-Fi) broadcast antennas on top of grain elevators in town and promote their service to those living in the surrounding countryside by stating, "If you can see our grain elevator, you can receive our wireless Internet service." Furthermore, a cell tower located in a rural county sends out a more powerful signal than a corresponding cell tower in an urban or suburban environment, because in the city, the tower is one of many in a "cell" configuration of coverage, much like a honeycomb, in order to saturate the city with uninterrupted coverage. A single

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[72] Doreen Carvajal, "Cloud of worry gathers over wireless health risks," *International Herald Tribune*, September 23, 2007, available at http://www.iht.com/articles/2007/09/23/news/wireless24.php.
[73] Geoffrey Lean, "EU calls for urgent action on wi-fi radiation," *The New Zealand Herald*, September 16, 2007, available at http://www.nzherald.co.nz/section/2/story.cfm?c_id=2&objectid=10463870.
[74] Geoffrey Lean, "Germany warns citizens to avoid using Wi-Fi," *The Independent*, September 9, 2007, available at http://environment.independent.co.uk/green_living/article2944417.ece.
[75] Joanna Bale, "Health fears lead schools to dismantle wireless networks," *The Times of London*, November 20, 2006, available at http://www.timesonline.co.uk/tol/life_and_style/education/article642575.ece.
[76] Geoffrey Lean, "Danger on the airwaves; Is the Wi-Fi revolution a health time bomb?", April 22, 2007, available at http://news.independent.co.uk/health/article2472140.ece.

tower in a rural county, however, has to cover much more acreage on its own and therefore needs to emit a more powerful signal. This exposes occupants in the immediate vicinity to a stronger influence than those living in a home near a tower in the urban environment (although within the city there are many more towers emitting different types of RF per square mile, so overall there is more exposure to RF in the city or suburbs).

People who are aware of the problem ask that our building materials shield us from potentially harmful broadcast frequencies, even at the expense of becoming isolated from helpful natural background radiation. Such protection from RF is particularly important for electromagnetically sensitive individuals, but our profession believes the public at large also benefits from the use of materials that block radio frequencies.

Fortunately many mineral-containing thick- and thin-wall envelope materials do provide a certain amount of protection.[77,78] Wireless Internet consultants state that conventional walls generally reduce an incoming wireless signal by 50%, which is a problem for them but a feature we use to our advantage. If one is sitting or sleeping in an inner room or a part of the house that has two walls separating them from a known outside broadcast tower or wireless Internet transmitting antenna, the incoming signal is effectively reduced by roughly 75%. Glass windows, however, do not block incoming RF signals to any significant degree, but window screen made of metal, not vinyl plastic, does. Specially coated, transparent RF-blocking plastic films are also available.[79] The latest developments in RF-shielding window film are reported in a June 26, 2007 article in *Scientific American*.[80]

To escape these electromagnetic waves, severely radio frequency-sensitive individuals resort to sleeping under special screening material suspended from the ceiling like mosquito netting or painting the inner surface of their bedroom walls with radio wave-blocking paint.[79] The Swedish government actually provides such materials for its citizens who are officially considered disabled due to electromagnetic sensitivity.[81,82]

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[77] Dietrich Moldan and Peter Pauli, “Reduzierung hochfrequenter Strahlung: Baustoffe und Abschirmmaterialen” (Reduction of high frequency radiation: building materials and shielding materials), originally published May 2000, revised January 2003; available directly from the authors at http://www.drmoldan.de/html/publikationen.htm. This publication presents results of RF-attenuation measurements on over one hundred different building materials.

[78] Robert Stellar, lecture presented at International Institute of Bau-biology® and Ecology Alumni conference, November 2006, Santa Fe, New Mexico.

[79] RF-blocking window film, RF-blocking paint, and RF-screening fabric are sold at www.safelivingtechnologies.com and www.lessemf.com.

[80] “IN FOCUS: Newly Declassified Window Film Keeps Out Hackers, Phone Calls, EMPs,” *Scientific American*, June 26, 2007; article available at http://www.sciam.com /article.cfm?chanID=sa004&articleID=6670BF9B-E7F2-99DF-3EAC1C6DC382972F.

[81] See the website of FEB - The Swedish Association for the Electrosensitive (Elöverkänsligas Riksförbund), http://www.feb.se/index_int.htm.

[82] British Broadcasting Corporation (BBC), “Wi-Fi: A Warning Signal”, on the Panorama show, May 21, 2007; transcript and video available for replay at http://news.bbc.co.uk /1/hi/programmes/panorama/6674675.stm.

Urban and suburban environments are increasingly bathed in low-level wireless "electrosmog" from many sources outside the home or office.[83] A building envelope made of mineral-containing materials that attenuates RF can directly absorb these frequencies and limit incoming radiation exposure far more than a home constructed in a conventional manner with wood framing, which lets much more of the RF through. Therefore using envelope materials that we recommend not only creates a safer environment for the electrosensitive individual, it also provides a measure of safety for the rest of the population who may also be adversely affected by these incoming radio frequencies.

One word of caution. Whenever you try using a cell phone inside a building made with RF-absorbing envelope materials, the cell phone signal is somewhat blocked and cannot reach the cell tower as easily. The phone is therefore automatically instructed by the tower to increase its power output to connect back with the cell tower outside. This happens whenever the cell phone antenna display bars are low, as is the case inside a home built with these materials, and consequently the user and others standing near them are exposed to higher levels of wireless signals. The same is true for the Wi-Fi on your laptop computer when you try to connect with a node outside your home. For that reason if you live and work inside such a home you should use caution when indoors using either a cell phone or Wi-Fi on your laptop. You are shielded from incoming broadcast RF, but as recommended above, it is prudent to use only hardwired telephone and high-speed Internet connections.

6.10 Natural Materials and Subtle Energies

Hubert Palm, one of the originators of Building Biology®, said that walls should be our "third skin" – our body's skin and clothing being the first two. He said that healthy walls should be a *living* entity and that therefore it is important they be made of natural materials.[84] Early building biologists propagated this point of view, and we are sympathetic to it, as indicated below.

However many conventional thinkers in the western world will take no stock in the idea that walls behave like living structures. Most of our European correspondents discount the idea of a living wall. Manuel Reig, a German architect, elegantly wrote that "'breathing walls' are not living organisms like riffs [*sic*, reefs] of corals, but constructions with a high importance for life." The reader may be content with a breathable, thick wall that satisfies all of the criteria already presented in this chapter and that is compatible with the principles discussed in the remainder of this book. They will find that to do so they will

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[83] Richard Latker, "Exposure to the invisible cloud of energy called electrosmog is rising"; *International Herald Tribune*, September 24, 2007; available at http://www.iht .com/articles/2007/09/23/business/wirelessbox.php.

[84] Hubert Palm, *das Gesundes* Haus (The Healthy House), Tenth edition, 1992; ©kOrdosan AG; Kösel, Kempten (1992), pp. 90-91. The first edition was published in 1968. *[The date may actually be earlier and we are trying to find out. –Ed.]*

need to use compatible natural materials[85] such as those recommended in this manual, regardless of whether or not they ascribe to Palm's theories. Even if they are inclined to skip to chapter 7, by now they should be grounded in the fundamentals of a breathable building envelope and ready to begin applying this knowledge in the design or building of healthy structures. But we do hope they will be open-minded and consider the following points of view that may enhance the understanding of how these walls work, especially as they apply to the justification for using compatible natural materials. The mechanisms presented below may in fact complement those given above for hygroscopicity and "breathing walls."

"Subtle energy" is a term of recent origin in the Western world, denoting a physical interaction that is not understood using conventional physics or is too small to measure using existing laboratory equipment. The most obvious and elusive examples pertain to the very nature of life. Subtle energy is also readily applicable to some extraordinarily weak bioelectromagnetic fields. For at least some of these observations rational explanations may be discovered some day. Bucking mainstream science and accusations of quackery, investigations continue in alternative circles. Some of these researchers embrace a "new biology" paradigm.[86] Meanwhile there are less scientifically oriented people who don't require proof.

There is a multitude of different ways to approach the topic of subtle energies. Traditional Eastern cultures don't have the "baggage" of science and view the compatibility of materials or forces as a "Yin-Yang" phenomenon, wherein for everything "Yin" there exists something complementary and interdependent that is "Yang."

According to Dr. Phil Callahan, author of *Paramagnetism: Rediscovering Nature's Secret Force of Growth* and numerous other books, one wants to combine Yin and Yang materials. Organic materials (wood, straw, hemp, etc.) are generally diamagnetic (Yin).[87] Inorganic materials (mineral or ceramic) can be diamagnetic or paramagnetic (Yang), depending upon whether ions (charged atoms) such as Fe^{3+} (the most common paramagnetic ion) are contained therein. Many soils contain paramagnetic Fe^{3+} but others are diamagnetic. Pure silica and lime are diamagnetic, for all the spins are paired. The same is true for magnesium oxide, but "doping" with $2Fe^{3+}$ (replacing $3Mg^{2+}$) produces a paramagnetic substance. Similarly, clay minerals can have either diamagnetic Si^{4+} or Ca^{2+} or Mg^{2+} in between the layers, making a diamagnetic substance, or Fe^{3+} making the mineral paramagnetic.

In this paradigm, cellulose in the form of wood chips, when bonded to clay or ceramic, has a diamagnetic-paramagnetic interface similar to that of tissue and bone in the human body. When combined together, they interact electronically to create a vital "push-pull" dynamic. This may be another explanation for the

[85] As will be seen in the remainder of Part Two, a *combination* of natural materials and judiciously chosen man-made materials may be necessary to build a healthy modern home.
[86] See for example the articles written by Bruce Lipton that we found posted at http://www.brucelipton.com/article/mind-over-genes-the-new-biology.
[87] If organic materials contain free radicals (generally but not always unstable) or certain bound inorganic complexes, then they are paramagnetic.

phenomenon known as hygroscopicity that enables the wall cavity to slowly pass water vapor, which is naturally present if a vapor barrier is not used. These same mechanics hold true for all of the wall materials we recommend in chapter 8.

Conventional walls, on the other hand, have unbalanced or non-existent electronic interactions between their component materials according to builder George Swanson, as they lack this diamagnetic-paramagnetic interface. In this paradigm, this is one of the mechanisms that contribute to the lack of movement of moisture in a wall, thereby helping to promote the deposition or condensation of free droplets of liquid water present inside the wall cavity, resulting in mold growth.

The push-pull phenomenon may be better understood if one considers the works of the noted American visionary, architect, designer and inventor, Buckminster Fuller. Fuller developed the "tensegrity" model, in which there is a balance between complementary forces. As explained in the Wikipedia page on this topic,[88] "Tensegrity is the name for a synergy between a co-existing pair of fundamental physical laws; of push and pull, and compression and tension, or repulsion and attraction." In one application of this model, biological cells contain the capacity to maintain homeostasis and self-regulate due to their ability to repel entropy, known as "syn-entropy." In this model the human body is one of the best examples of syn-entropic forces. For example, when you replace a section of bone with plastic, then blood will generally not flow next to it. According to George, push-pull interactions between different natural building materials have similar mechanics as syn-entropic living systems.

Another pertinent view based on syn-entropic forces was offered by the Austrian naturalist, scientist and inventor, Viktor Schauberger. In order to understand the importance of push-pull interactions, Schauberger refers to upwardly vortical or levitational energies, as in his example of "floating rocks." There are several books that nicely describe the large body of research by Schauberger.[89]

Applying this understanding to the composition of conventional walls, builder George says that a plastic vapor barrier, when placed next to virtually any building material, significantly lessens the subtle interactions between natural building materials. He notes that the presence of a vapor barrier actually causes cellulose to lose its diffusion properties because the proximity of plastic suppresses any significant movement of molecules of water vapor through the cellulose.

This lack of a push-pull dynamic within a wall containing a plastic vapor barrier may be one more reason why mold loves to grow in a conventional wall. George states that the minute you reintroduce these subtler mechanics allowing the

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[88] See http://en.wikipedia.org/wiki/Tensegrity.

[89] We recommend all of the following, although the third is accessible to the widest audience.
(a) Callum Coats, *Living Energies*, Second edition, Gateway (2002);
(b) Olof Alexandersson, *Living Water: Viktor Schauberger and the Secrets of Natural Energy*, Second edition, Newleaf (2002);
(c) Alick Bartholomew, *Hidden Nature: The Startling Insights of Viktor Schauberger*, Adventures Unlimited Press (2005).

gradual movement of air into the wall through slow diffusion, mold cannot grow. Instead, in such a vital, "living" wall you reestablish a push-pull dynamic in which any moisture that is introduced can fully move through and dry out, disallowing mold growth without loss of thermal performance. This subtler understanding may therefore complement the more conventional explanation we already have for wall material moisture regulation through hygroscopicity, permeability, diffusion, adsorption and capillarity.

Lastly, we would be remiss not to mention *electrostatic charging*, which is a well-accepted phenomenon in mainstream physics. Natural materials are weakly negatively charged. By contrast plastics and most synthetic building materials are strongly positively charged. As a result, plastic vapor barriers alter the naturally negative ion balance of the air within and surrounding wall cavities. This creates DC electric fields that may directly affect biological systems and the health of the residents. The maximum acceptable surface potential on building materials is less than 100 volts DC, according to the official international Building Biology® standard published by the Institut für Baubiologie und Ökologie Neubeuern (IBN). At higher voltages sensitive people may be affected. Indeed, damage to electronic parts may be observed above this limit, and there is no reason to believe that biological systems are less susceptible. For the most part only natural materials are compliant with this standard.

Chapter 7. Water Intrusion and Condensation Problems in Conventional, Energy-Efficient Wood Frame Construction

7.1 Introduction

Now that you understand the desired properties of a wall system as we see it, let us examine how well today's building industry fulfills those goals. In the area of water intrusion, the report card is not so good. Valiant attempts have been made to correct the situation with unsatisfying results. In this chapter we provide a detailed review of the problem and end by offering specific solutions using the materials and approaches recommended by our profession.

Practicing building biologists and mold investigators around the country are finding that current wood-frame construction is rife with mold that often affects the health of occupants. Mold grows because walls constructed with plastic vapor retarders (less rigorously known as "vapor barriers") and house wrap with fiberglass as the insulation do not allow moisture trapped within them to fully and easily dry out.

Moisture generally enters modern wall cavities in two ways. The first is direct rainwater intrusion from the outside. The second is leakage of moisture-laden interior air through interior sheeting materials, including plastic barriers. Whichever way moisture enters a wall, once it does so it can cause mold and structural damage, if the wall cavity cannot dry out. The problem is compounded by the use of materials that decompose rather than simply drying out when they become wet. We shall also see that, despite efforts to keep liquid water and water vapor out of walls, plastic house wrap and vapor retarders themselves can fail as moisture barriers.

We take the time to explore this issue for one important reason. Wood frame thin-wall construction is pervasive in this country and so is the idea that a vapor retarder is absolutely necessary. Yet mold is pervasive as well. The problem is that builders still adhere to the notion that the only way to solve the problem is to tighten the house even more in a valiant attempt to keep moisture completely out. Even those pushing to become "greener" try to keep the walls tight. Unfortunately, doing so is simply not possible. The sad reality is that when conventionally built walls fail, they fail in a big way, leaving homeowners sick and financially strapped trying to fix them.

The Building Biology® profession, on the other hand, offers alternatives that stand outside mainstream thinking and are not known by most conventional builders and architects. We join a small but growing subset of builders who recommend wall systems that provide a realistic solution to water intrusion and mold issues while providing thermal performance, durability and increased health for occupants.

Let us first discuss how mold grows and then consider the extent of the problem.

7.2 Mycology

To fully understand water intrusion and condensation and the problems they create, it is helpful to know some basic facts about mold growth. Larry Gust, a Ventura, California building biologist, tells us why the first 24 hours is critical:

1. Fungal growth starts with a small number of dormant spores that are ever present within the indoor environment, having entered over a period of months or years. Some of these spores are viable while others are not.
2. Upon moistening with water, these preexisting spores begin to grow long, branching filaments called *hyphae*.
3. If the fungal life cycle is not interrupted, the hyphae proceed to grow stalks called *conidiophores*.
4. The conidiophores grow and release new *conidiospores*, or "spores," which are capable of renewing the life cycle.
5. Spores produced and ejected are blown away by the indoor air to other locations. (When the environment dries, more spores are ejected.)
6. The fungus is vulnerable at the early stages of germination, when the only things that would be growing beyond the original spore and germ tube (and maybe a couple of mitotic divisions) would be yeasts, which are not harmful to people or pets. These will not survive without continuing moisture.
7. Later on it becomes progressively more difficult to stop further growth because many spores will have grown protective walls. At this point we're on the steep part of the exponential growth curve. This is a dangerous situation for the homeowner.

It is generally accepted that mold needs three ingredients for optimal growth: (1) a bio-film as a food source, present on virtually every surface on earth; (2) moisture; and (3) low air flow. Many experts also include a fourth on this list, darkness, although there are some species that require light to sporulate.

Since the food source cannot realistically be eliminated, mold growth is controlled primarily by keeping materials dry and providing good air circulation. In order to accomplish this without excessive heat loss, thick envelope materials are a wise choice because they possess the capacity to allow drying and slow air circulation through hygroscopic adsorption/desorption, vapor permeability and diffusion, and capillary absorption/desorption, all mechanisms discussed in detail in the preceding chapter. To modern builders this is a novel concept not thought possible, but it is practiced by old-timers in the trade.

As noted above, mold spores can start to germinate within a few hours of the wetting of building materials, whether in a wall or elsewhere in the home. All materials are susceptible, except for sheet metal used in air ducts, upon which it is said mold generally will not grow. (Builders claim, however, that they have seen mold growing even in metal air ducts.) Peter Sierck, mold expert and building biologist in Carlsbad, California, would add plastic laminate to the list of materials that he feels do not support mold growth. Every other building material is fair game (with the notable exception of the breathing wall materials introduced in the next chapter).

Mycologists generally say, if you can stop a fungus when it has just germinated, then it will die, because this is their most vulnerable stage. If they are allowed to grow, they develop protective walls and are harder to eradicate. Building materials can sustain structural damage as a result, and occupants suffer health symptoms.

Therefore, if water restoration efforts are begun within the first 24 hours, materials should be salvageable because under most conditions the mold has not yet produced spores. There may be residual dead mold, but it is not a health threat. Peter Sierck, the mold expert from California, states that even though it takes up to three to five days for mold growth to become visible to the eye, the immediate water damage must be addressed within the first 24-48 hours before the mold starts to colonize.

If wet wall cavity materials do not dry out within that critical first 24-48 hours, however, then massive spore formation may occur and the number of mold colonies grows to the point of no return. At that point, all wet, porous surfaces must be removed. This includes organic materials that readily absorb water, including sheetrock, batt or loose fill insulation, and carpet and its padding. Flooded water will even wick up sheetrock and insulation, causing damage several feet above the original water level on the floor.

For other materials such as wood framing elements, brick or concrete that are partially open to capillary absorption, many mold experts, such as Sierck, recommend abrasive removal of mold using sanding or a wire brush under carefully controlled conditions. Other mycologists recommend full removal of even wood structural elements if they have sustained mold growth.

All recommend that you create as little dust as possible using HEPA-vacuum saws and careful containment practices, following guidelines from the EPA (Environmental Protection Agency; www.epa.gov) and the IICRC (Institute of Inspection, Cleaning, and Restoration Certification; www.iicrc.org). This usually requires professional care by certified mold remediators.

Non-porous surfaces (sheet metal, glass) need to be carefully wiped down. We recommend using fungicides that are not harmful to people, including The Wellness Company's Sol-u-Mel®, containing melaleuca or tea tree oil (www.melaleuca.com), used by FEMA nationwide for their flood clean-up jobs; HydrOxi Pro®, containing hydrogen peroxide and citrus (www.core productsco.com); Young Living's Thieves Oil Blend (www.youngliving.com);[90] or Scott's Liquid Gold® Mold Control 500, a quaternary ammonium

[90] Thieves Oil Blend is available as either a ready-to-use cleanser or as oil that can be diffused through the air. Both can be obtained locally through distributors listed on the Young Living website, or from many different sources on the Internet

compound.[91] One can also fog with Sanifect-128®, available from HAZARiD (800-675-0323; www.hazarid.com), another quaternary ammonium compound, as discussed in section 7.9 below. These quaternary ammonium compounds are nontoxic after application.

However Peter Sierck says the goal is not to just kill the mold. Physical removal is most important. He says that the use of fungicides alone is not a substitute for physical removal and replacement of infected and damaged building materials.

Water-based encapsulants can then be used on non-porous surfaces that remain in place. We recommend a nontoxic product called Safe Encasement® (www.safeencasement.com), which can also be used to encase lead and asbestos.

As practicing building biologists and mold experts know, many clients who have had previous water damage are reluctant or financially unable to remove materials that were once exposed to rainwater intrusion or a plumbing leak. Homeowners assume that once the materials have dried out, everything is fine. They are still at risk, however, because when wet materials dry out, dormant mold spores are still present and remain a health hazard. According to Larry Gust, the California building biologist, “Those [spores] remaining in the no water area go dormant and wait for the next moisture event. Some die waiting while others survive for many, many years.”

The problem for homeowners is that even when dormant, these mold spores can be allergenic and toxigenic, according to Sierck. Active mold spores produce harmful metabolic by-products called mycotoxins. When these spores become dry and dormant, they are still toxic and cause illness when dispersed into the air and inhaled by occupants. To make matters worse, mycotoxins are not neutralized when mold spores are killed by most fungicides, according to Sierck, another reason to remove infected materials after they have dried out.

The presence of a vapor retarder can help delay the movement of dormant mold spores from within a wall cavity into indoor air, but these spores can eventually be inhaled by occupants, often causing unexplained symptoms and illness. This can include allergies, respiratory infections, immunosuppression, memory loss and headaches. Mold sources can be hidden within the wall cavities. It is not uncommon for forensic experts to open wall cavities during their investigations to discover mold sources where exterior and interior finishes may not yet be reflecting damages. Occupants may be experiencing symptoms from these hidden sources prior to visible evidence of possible wall cavity proliferation.

For these reasons, mold experts recommend the removal of *all* water-damaged building materials after a water intrusion event, whether still wet or dried out. Those wanting to build a new home can avoid this altogether by designing and

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[91] Mold Control 500 is described in an April 27, 2007 manufacturer’s press release at http://www.deconsolutions.com/SNL%20Press%20Release.html, and on the product website, http://www.scottsliquidgold.com/mold-control-500/. Unlike other fungicides this product is supposed to decompose mycotoxins as well as kill the mold. Beware that, unlike the first three alternatives, MC 500 is a strong oxidizer requiring safety measures when applied, but the active components do break down within hours rendering them nontoxic.

building wall and foundation systems that do not trap moisture in the first place. Build walls that allow moisture to dry out within the critical first 24 to 48-hour period while maintaining superior thermal performance. The systems recommended in this manual do just that.

7.3 The extent of the problem

News reports such as a May 13, 2007 article in the Minneapolis Star Tribune[92] entitled, "Water Woes," document the large number of homes that are literally rotting from within because moisture that seeps into walls cannot escape. Most of the homes built throughout the nation in the 1990s used non-breathable materials. Additionally, improper techniques were used in many homes in installing windows, decks and roofs. Structural damage and mold has often been the result, and repairing damaged walls can be quite costly. The article indicated that moisture that had accumulated over years under non-breathable stucco caused substantial structural damage and mold costing homeowners hundreds of thousands of dollars to correct.

Louise Goldberg, an engineer at the University of Minnesota, was quoted in the article as saying, "The fact is, the waterproofing systems in these homes have failed…. If the windows leak or the waterproofing is installed incorrectly, you have a failure condition." She and other experts interviewed for the article stated that the materials chosen did not dry out when water entered due to improper installation. Goldberg also stated that, "Older stucco homes don't have these problems because different construction materials and methods allow them to breathe."

Oak Ridge National Laboratories says:

> If moisture accumulates above a critical material-dependent threshold, the building components begin to rot, corrode, or otherwise degrade in structural or functional integrity. Damage induced by moisture includes rotting of wood studs and other components, corrosion of steel frame members, salt transport, mold growth, and efflorescence. Such damage is related to the inability of the building owner to control moisture within acceptable limits.[93]

Neil Carlson, Industrial Hygienist and mold expert for the University of Minnesota, states that a good percentage of the current building stock will "self-compost" in ten years from mold formation due to improper construction. News reports throughout the country echo these sad statistics. Articles abound with story after story of homeowners moving into expensive new homes, only to have mold develop with no recourse from the builder or insurance carrier to help remedy the situation. The burden to fix the problem falls on the ill homeowner who cannot sell their house and must live in moldy conditions because they often cannot afford to live elsewhere.

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[92] Jackie Crosby, "Water Woes," May 13, 2007, www.startribune.com.
[93] See http://www.ornl.gov/sci/roofs+walls/research/envelope.htm.

As noted in the introduction, moisture in wall cavities enters not just via condensation of moist indoor air, but by rainwater intrusion from the outside because of poor construction technique. Two examples of that are improper application of flashing around windows and installation of siding without an air gap behind it. The problem is made worse by building practices, mandated by code throughout the country, that require homes to be airtight, virtually ensuring that moisture that inevitably gets into walls cannot dry out.

Water intrusion and mold growth can occur in conventionally constructed walls as early as the first one to two years. This happens sooner if the vapor retarders are sealed very tightly. A tight taping job results in rampant mold growth once water vapor leaks through small defects that inevitably occur in wall taping jobs. We discuss this in detail below. Two years is enough time to prevent a clear connection from being made between the water vapor seepage (with its resultant mold) and the developer who built the house. There are reports of developers who, to evade litigation, dissolve their entire companies and form new ones in cycles as short as every two years in order to avoid direct responsibility for repairing the homes they have built. More recently builders are requiring homeowners to sign waivers holding builders harmless for any mold growth after occupancy. Unfortunately the fault lies with the designer, who created a flawed design, as well as the builder, because of improper construction.

Some experts even claim this problem could potentially involve every conventionally-built home constructed in the past 15 to 20 years, regardless of price or choice of building materials. George is of this opinion. They notice that both interior and exterior walls look "pristine," yet in many cases the walls are "rotting away" on the inside. Some building forensic experts conservatively estimate that up to 50% of housing units built in the 1990's are experiencing water intrusion issues in certain parts of the country. This is largely due to the fact that the relevant building codes at the time did not require a water resistive membrane under the exterior finish system of the house when 'exterior exposure' type sheathing was used. This estimate is corroborated by a study conducted by Marilou Cheple of the University of Minnesota which found that of new homes studied that were built in the 1990s, more than one half had three or more indicators of potential moisture problems.[94]

Austin, Texas led the way with green building and energy-saving protocols by making vapor retarders mandatory in the 1980s and early 90s. They are also the first city in the country to ban their use in wall construction, which occurred in the mid-1990s, a direct reversal of their earlier mandate. Many other cities now make vapor retarders optional. Contrary to building code in many jurisdictions in the northern USA that require vapor retarders, Canadian provinces do not require them. As a result of the prevalence of mold in new homes, municipalities across the United States are now recognizing and beginning to deal with the issue of water intrusion.

According to George, builders today who use a Structural Insulated Panel System (SIPS) may be creating conditions for mold growth. SIPS panels contain rigid plastic foam cores covered on either side by Oriented Strand Board (OSB) or

[94] "Moisture Problems in Houses Built in 1991 and 1992 in Minnesota," Marilou Cheple, Becky Love Yust, University of Minnesota

plywood. George has inspected homes made with these materials and found that the walls often have excessive moisture buildup at the seams when not extremely well sealed. As a result moisture leaks all around the panels and remains at the interface between materials within the panel, creating the potential for mold growth. Even if well sealed, George recommends against using traditional SIPS construction in favor of materials that "breathe." Finally, he says that if the core insulating material, such as rigid foam, is not breathable, then at least the sheeting materials surrounding the core should be, in order to avoid mold. Magnesium oxide boards, discussed in the next chapter, are an exciting alternative to OSB and plywood that is fully breathable.

Exterior Insulation and Finish Systems (EIFS), another popular building technology, are made with synthetic stucco and extruded polystyrene. George feels this is the most mold-producing system ever designed. He has seen solid black mold growing on the inside of extruded polystyrene after 15-20 years of freeze-thaw cycles, causing the material to decompose into what he describes as "black goo."

The newest forms of EIFS often require "breathing" moisture control mats between layers to prevent mold and if done properly can cost up to $12 per square foot. In addition, many synthetic stuccos are now designed to be semi-permeable. While this is an improvement, George worries that the plastic pores may still fatigue over the years from repeated freeze-thaw cycles and severe heat, leading eventually to product failure such as occurs with plastic house wrap (see below).

To further illustrate the point, the Wall Street Journal reported on a class action lawsuit against the makers of plastic stucco. The total was up to $11 billion as of 2003. The materials in these walls are decomposing simply because they do not allow the moisture to dry out.

The so-called "concrete house," also known as an ICF or insulating concrete forming system, is very popular these days and has the advantage of increased thermal mass when compared to wood frame walls. However we recommend you avoid conventional ICFs with polystyrene jackets surrounding a concrete core because they are only marginally able to "breathe." Moisture can often accumulate on the inside of these walls, and in isolated cases George has observed mold growth. This is because moisture is inevitably trapped in the layers between the rigid foam jacket and the concrete core, similar to the SIPS panels mentioned above. In spite of manufacturers designing a waterproof outer foam jacket and their advertising to the contrary, moisture inevitably finds its way into the space between that layer and the concrete core by capillary action and water vapor condensation. Once that happens, the moisture cannot dry out, resulting in mold growth. Fortunately there is a little-known but breathable ICF alternative available, in which the jacket is made of cement-bonded wood fiber. We highly recommended this option, also known as low-density fiber-cement, and discuss the material in detail beginning in section 8.8.

7.4 Historical background

Mold growth was not a significant problem in the initial decades after the widespread introduction of vapor retarders in the 1960s.[95] This occurred primarily for two reasons. The first was the continued use of inexpensive doors and windows that leaked enough to allow indoor air and air within a wall cavity to exchange with the outside. While the amount of energy used to heat and cool a home was higher back then, any moisture that entered the wall cavity could easily dry out. (On the contrary, well-fitting doors and windows are essential for the success of breathable, thick-wall construction – see section 14.5.)

The second reason why mold growth in walls was not a serious problem decades ago was the presence of large defects within the vapor retarders themselves, mostly due to a faulty taping job. Carpenters who remodel homes today built in the 1960s, '70s and '80s, and especially walls built in the first half of the last century, generally report not seeing mold when they open walls. The problem, they say, started in the mid- to late 1990s, when building codes first required tighter vapor retarders. Although carpenters today rarely open walls built just ten years ago because the houses don't need remodeling, mold experts *are* having to open these walls to investigate why occupants are sick, finding mold in the majority of cases.

A third problem, according to Minnesota remodeler Gene Eldeen (952-435-2148; everlastinghome@comcast.net) is the use of softwood lumber for window framing and the fact that most windows are not well maintained over the decades. Gene says many windows built from the 1800s through the 1940s were made out of white oak, a wood that is inherently rot-resistant when exposed to moisture. The paint covering it may peel over the years, but the wood will not rot. Window frames built during that period are still intact today. Softer woods such as pine, which rot when paint and caulk fail, were introduced in the 1950s. Particleboard, a porous material that is also rot-prone, was introduced in the 1970s.

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[95] For a brief history of the plastic vapor retarder, we quote from an informative article by Mark D. Lawton and William C. Brown, "Considering the Use of Polyethylene Vapour Barriers in Temperate Climates," *Building Envelope Forum,* 5th Edition online newsletter, June 2006, posted at http://www.buildingenvelopeforum.com/pdf/newvaporbarrier.pdf: "The primary purpose of a vapour barrier is to control the transport of water vapour by diffusion. Rose provided a history on both the conceptual development and physical application of vapour barriers in the United States, tracing some of the concepts to ASHRAE publications of the 1920s and 1930s. Rose attributed the application of diffusion theory to insulated buildings and the development of the concept of a vapour barrier to Rowley in the period between the 1930s and World War II. In Canada, research into vapour diffusion control by the National Research Council extends back to the 1940s." The historical paper cited by Lawton and Brown is the following: Rose, W. 1997. "Control of Moisture in the Modern Building Envelope: The History of the Vapor Barrier in the United States – 1923-1952." *APT Bulletin*, Vol. XVIII, No. 4, October 1997 (Association for Preservation Technology). Lawton and Brown also cited two classic National Research Council tutorials, originally published in the Canadian Building Digest which are currently available online: G. O. Handegord, "Vapour Barriers in Home Construction," September 1960, http://irc.nrc-cnrc.gc.ca/pubs/cbd/cbd009_e.html; A. G. Wilson, "Air Leakage in Buildings," November 1961, http://irc.nrc-cnrc.gc.ca/pubs/cbd/cbd023_e.html.

Finally, according to design-build remodeler Kel Heyl of St. Paul (612-772-603; www.studiorebus.com), the '80s began a time when on-site workers were likely to be have less training and be less closely supervised than their earlier counterparts, with no history of the craft. Kel, a trained carpenter, says, "In the 1980s and '90s the trades died. The whole idea of building something to last with craft and artisanship was lost." This led to poor workmanship and the ability of moisture to easily penetrate walls that were designed to be airtight and were unable to dry out in time to prevent mold. Kel also says he has never seen any evidence of mold or water damage in walls he has opened in older homes built in the earlier part of the last century, because they always dried out when they became wet.

We turn next to one of the major causes of water vapor intrusion and mold in walls, in our opinion.

7.5 Why We Recommend No Plastic Vapor Diffusion Retarder

We believe builders should not use plastic vapor diffusion retarders (commonly, but less accurately, known as "vapor barriers") for the simple reason that once moisture enters a wall, it cannot dry out. Yet conventional modern walls prevent this from happening. However valid the *concept* of a vapor retarder keeping moisture out of a wall may seem to be, many builders and mold experts alike have discovered that tight vapor retarders actually *encourage* mold to grow. This is because they end up promoting the very problem they are designed to prevent.

Joseph Lstiburek (pronounced "SEE-burek"), one of the premier advocates of building science in the building trade, does not recommend sheet polyethylene as a vapor diffusion retarder in his EEBA Builder's Guides[96] for any climate except the severe cold, encompassing only the top half of Maine, the upper Midwestern and mountain states and all of Canada. Yet builders have been using plastic vapor retarders throughout much of the USA and it is required by many building codes.

In the words of Neil Carlson of the University of Minnesota, all buildings, regardless of age, will sustain at least one water intrusion event at some point in their lifespan. For that reason, we believe the ability of walls to naturally dry out when first exposed to moisture must be designed into the envelope. This can be done in such a way that the benefits of a wall are not compromised, including the self-regulation of moisture year round and the storage, radiation and optimally-phased distribution of heat and cool.

We agree that the only way a conventional wall, built in a cold climate with wood framing and spun glass insulation, can avoid mold growth is to have vapor diffusion and air flow retarders installed on the warm side *without defects* and the wall cavity must *truly* dry to the outside. Yet both goals rarely happen in the real world. In the words of one builder, the minute you drive one nail into a wall to hang a picture or even staple the polyethylene sheet to the studs in the first place,

[96] These guides are available from the Energy and Environmental Building Association (EEBA), 952-881-1098; www.eeba.org.

you have perforated the vapor retarder and moisture will migrate in. We offer more practical alternatives because failure to build these walls properly can result in substantial illness to homeowners from mold growth.

To better understand this process, water vapor normally moves from the warm side of a wall to the cold side. The direction reverses depending upon the season. According to building science,[97] moisture intrusion is driven by two forces: diffusion of water vapor through wall materials, which is a relatively small effect, and direct migration of moisture-laden air, through holes and penetrations. Diffusion through materials is in turn affected by two phenomena: differences in vapor pressure and differences in temperature. These concepts were introduced above in section 6.3.

In practice, vapor diffusion retarders are not the same as air flow retarders (known in building code language as "wind wash barriers"). In general, a vapor diffusion retarder prevents condensation of moisture, while an air barrier prevents heat loss and maintains energy efficiency. Historically, polyethylene sheets were mandated by code as both the functioning vapor retarder *and* the air, or wind wash, barrier, and this concept is still strong in the minds of builders. It is important to distinguish between vapor retardance, water intrusion, and wind infiltration.

An effective retarder of vapor does not necessarily stop air flow and does not need to be airtight. The amount of vapor diffusion prevented by a plastic retarder is dependent upon the area covered. Thus if there are holes and tears in 5% of a vapor diffusion retarder, such as sheet polyethylene installed between wallboard and wood studs, it will still be 95% effective at preventing water vapor diffusion right through the wallboard material.[98]

The problem comes when you have one or more holes in an *air flow* retarder allowing moisture-laden air to enter the wall. The amount of water deposited over the course of a winter from warm, moist indoor air flowing through a small hole in a wall built for a cold climate can be astounding. Building inspectors have seen as much as two inches of standing water when they open plastic-lined wall cavities. Laboratory experiments have shown that if there is a pressure differential of at least 10 Pascals of air leakage through a one square inch hole in a 4 by 8 foot sheet of gypsum board can, over the entire heating season, deposit up to 30 quarts of moisture into a wall cavity built for a cold climate. The indoor air was kept at 70 °F and the relative humidity at 40% during the test[99]. Thus defects in air flow retarders can be up to 100 times more of a problem than diffusion of water vapor directly through wall materials.[100]

This explains George's observation that the more you tighten a wall, the more chance you have of condensation and mold growth. In his experience, either a wall needs to be perfectly sealed on the interior with a vapor diffusion and air flow retarder *and* perfectly sealed on the exterior from all water intrusion, both of

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[97] Joseph Lstiburek, *Builders Guide to Cold Climates*, Energy and Environmental Building Association (EEBA), Eden Prairie, MN, 2001 edition, p. 274.
[98] Ibid., p. 278.
[99] Ibid., pp. 278, 288.
[100] Ibid., p. 276.

which almost never happen, or the entire wall must be highly breathable. Anything in between these two paradigms creates a moldy wall at some point because virtually all vapor and air barriers and measures to inhibit water intrusion from the outside fail at some point.

The problem arises from the fact that a perfect seal is never achieved in modern walls built with a plastic vapor and air flow retarder, no matter how valid the concept may be on paper. When the taping job is very tight, the defects that remain in the air flow retarder are naturally smaller. As a practical observation, George has noted that the smaller the defects become, the more moisture ends up in the wall cavity. He says, for all practical purposes you cannot seal a wall, you can only end up decreasing the number of small orifices until moisture enters "with a vengeance" through those that remain. George surmises that the pressure of the system trying to equalize itself across the plastic layer increases the forces that push moisture-laden air into the cavity. Moisture then dries out far more slowly due to the near perfect vapor seal you have created with the air and vapor retarder.

George has witnessed that in the case of small defects within vapor retarders, these forces have resulted in massive water intrusion and extensive mold colonies on the cold side of the retarder, consistent with the observations of building science experts. George was asked to consult several years ago on new tightly insulated homes in Saskatchewan, Canada that had developed mold. All were highly energy-efficient and built using standard modern building practices. The homes had plastic vapor retarders installed in wall cavities rated at R-45 with ceiling insulation rated at R-70. Mid-winter outdoor temperatures averaged -30 °F for the entire three weeks during the inspection period.

When he opened the walls George found that some of the houses had massive amounts of condensed water behind their vapor retarders with formation of large mold colonies. In every case the moisture intrusion was traced to very small defects. The third largest insurer in Canada filed for bankruptcy as a result of having to pay for demolition and rebuilding of these and similarly damaged homes throughout their country, even though they were only one to two months old. Similar stories abound in this country.

Remodeler Shesh Andahl of Andahl Construction in Minneapolis likewise tells of her experience with many expensive new homes with exterior walls that had to be completely rebuilt because of mold growth. As with George's observation in Canada, she reports that the moisture intrusion was traced to defects in the vapor retarder no bigger than a silver dollar in virtually all cases. Other remodelers echo this sentiment.

In order to combat the problem, modern builders rely on a combination of vapor diffusion materials, air flow retarders, and strict control of indoor air pressure and moisture levels. Air pressures are kept slightly negative in winter and slightly positive in summer. The conventional thinking is that, the tighter and more impermeable the building envelope, the easier it is to control internal air pressure and humidity.[101] In northern climates, the solution in winter is keeping indoor relative humidity within acceptable limits, putting the onus on homeowners to

[101] Ibid., p. 278.

carefully monitor living habits, and relying on mechanical equipment to always function properly.[102]

Once again, these approaches are reasonable in theory and work for some families and homes. Yet in our opinion, it is not realistic to expect homeowners to consistently use bathroom and kitchen exhaust fans and always take other steps to keep indoor humidity sufficiently low. The introduction of air-to-air heat exchangers, also known as heat recovery ventilators or HRVs, has helped by exchanging indoor air and reducing humidity in winter. HRVs are now required by code in new homes in some states but many homes lined with plastic vapor and air retarders do not have them, meaning that it is not easy to control indoor air pressures.

The use of breathable wall materials avoids all this because, by virtue of their design and construction, the walls readily dry out when they become wet and they do not support mold growth. One is also not reliant on mechanical ventilation systems. In walls built with breathable materials but without a vapor retarder, the forces of vapor pressure are allowed to diffuse and equalize over the entire surface of the wall rather than concentrate around a small defect that inevitably results from a taped plastic vapor retarder. With breathable walls, the entire wall system takes care of diffusion. Our walls work with, not against, the forces of nature.

Manufacturers of thick wall materials do strongly recommend a continuous air (or wind wash) barrier for optimal performance, but this can be satisfied with a continuous sand and cement parging layer and/or continuous multiple coats of natural stucco material, both of which are applied to the external surface of the block or wall form and are fully breathable. This is discussed in detail in section 9.7.

The next section addresses how rainwater intrusion in wood frame structures has become such a pervasive problem and what can be done about it.

7.6 Rainwater Intrusion into Wall Cavities

There are several mechanisms which inherently increase the potential of water intruding into the wall cavity and damaging materials.

Missing Air Gap over Drainage Plane

One of these mechanisms of intrusion is the capillary action of rainwater through the house wrap type membrane when certain types of cladding or siding are fastened directly against the house wrap without an air gap. Moisture will then move inward to moisten or even saturate the underlying sheathing and potentially move into the wall cavity.

Paul Fisette, Director of Building Materials and Wood Technology at the University of Massachusetts, Amherst (413-545-1771; pfisette@forwild .umass.edu), indicates that “panel siding, T 111, and board siding lay flat against

[102] Ibid., p. 274.

the sheathing wrap and do not provide any drainage or drying space. Water that gets past the siding can remain trapped between the siding and wrap for longer periods of time, raising the potential for moisture problems."[103]

To remedy this, many building science experts recommend an air gap or drainage plane, also known as a vented rain screen, behind the cladding (at least in climates with moderate to heavy rainfall of over 30 inches per year).[104] Many builders are also now adopting this drainage plane technique and it can be accomplished in several ways. This air gap is created by nailing furring strips directly over house wrap or building paper, or by using a manufactured plastic mesh, such as Home Slicker made by The Benjamin Obdyke Company (800-346-7655; www.benjaminobdyke.com). (We do not recommend metal mesh due to electric and magnetic field exposure issues.) According to the National Association of Home Builders Research Center's Toolbase Services,[105] ⅜ inch is the minimum space needed to avoid movement of moisture across the gap by capillary action and to achieve equalization of pressure from wind.

Paul Fisette goes on to say that "The area directly behind a wind-blown wall surface is at a lower pressure than its exterior face. This pressure difference works to suck the water inward through any hole it finds." The presence of an air gap, on the other hand, equalizes this pressure, eliminating the forces that drive rainwater behind siding. Secondly the air gap allows water to dry much more readily than water trapped behind siding nailed right against the sheathing.

To complete the vented rain screen system in today's standard wood frame housing, there must be a water resistive membrane behind the air gap that covers and protects the sheathing underneath. This must be layered shingle fashion and overlapped such that water stays to the outside as it drips down by gravity and out at the bottom. Builders have been choosing either plastic house wrap or building paper. George and others recommend the use of building paper because plastic retarders often fail to be semi-permeable as designed. They are supposed to allow water vapor to escape from the inside but to be relatively impervious (capillary closed) to rainwater intrusion from the outside, yet they lose the ability to breathe to the outside over time. We discuss this in detail in the next section.

Richard Wheeler, a building science-based consultant and CFO of Residential Science Resources in Hampton, Minnesota (612-822-8529; www.residentialscience.com), agrees, saying that you need a drainage plane for pressure relief behind exterior cladding. He recommends following the EEBA cold climate guidelines to create an air space behind most cladding in wood-frame construction, especially brick and stucco.[106] He says you still need an air gap even if you use Hardiplank® and Double D building paper, which is far preferable from our standpoint than vinyl or aluminum siding over plastic house wrap.

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[103] Paul Fisette, "Housewraps, Felt Paper and Weather Penetration Barriers," © 2001, http://www.umass.edu/bmatwt/publications/articles/housewraps_feltpaper_weather_penetration_barriers.html.
[104] For an Annual Rainfall Map and recommended drainage protocols; see the *Builder's Guide for Cold Climates*, pp. 232-243.
[105] See http://www.toolbase.org/Technology-Inventory/walls/rain-screen-exterior-walls.
[106] J. Lstiburek, *Builders Guide to Cold Climates*, p. 232-243.

Rainwater that penetrates the cladding can now drain down the drainage plane along this air gap and out the bottom of the wall. Without the gap, moisture from wind-driven rain that gets behind the siding can saturate the water resistive membrane and wet the sheathing. This air gap must be properly constructed and designed to release the water above the ground. This is discussed further in the next section. Otherwise problems will develop. As Toolbase Services states, "Water accumulation problems that occur with barrier EIFS can also occur with drainable systems if design or installation is not correct. Water intrusion, impact damage, cracking, adhesion failure, finish delamination, and staining from dirt, mold, or mildew can occur."[107]

Vented rain screen designs are not yet mandated by building code according to Toolbase Services,[105] but many jurisdictions are considering adopting them. We discuss this below.

Running Siding Down to and Into the Ground

A second mechanism which increases the potential of rainwater intrusion is installing the exterior finish system all the way down to and into the ground. This is particularly an issue with stucco finishes. For stucco finishes, the building code has required termination and release above grade for decades. When terminated below grade, water behind the siding system cannot release and can migrate past the water resistive membrane.

To solve this second major mistake, you must expose several inches of foundation below the bottom of the exterior cladding.

These problems don't occur if you use the breathable, thick wall materials that we recommend because you can apply natural stucco directly over low-density fiber-cement wall forms that can be used from below grade to above grade. According to George, who has built many homes in the colder climate of the upper Midwest, you do not need an air gap behind natural stucco applied directly to cement-bonded wood fiber wall forms because the forms can dry out, even with wind- and sun-driven moisture migration into the wall. Also, if you do attach cladding, including stone or brick veneer, to thick wall forms, you still do not need to create an air gap because the wall itself can handle any moisture that penetrates the cladding. This is explored in detail in chapter 8.

Missing Kick-Out Flashing and Water Management

A third mechanism which increases the potential of rainwater intrusion is the lack of diversion and collection of roof run-off storm water on the facets of the wall plane. During heavy rains, water pours over the edge of the sloped roof and cascades onto the vertical wall below. The exterior wall finishes below are often stressed or unable to resist this increase burden of water.

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[107] See http://www.toolbase.org/TechInventory/TechDetails.aspx?ContentDetailID=988&BucketID=6&CategoryID=54.

Kick-out diverters, mounted near the roof edge divert the water from the wall plane below. It is important that gutters are also employed for water collection to move this water away from the wall. Even when kick-outs are employed, wind can drive the rain water back over the wall finish.

Kick out flashing is now code in many states for certain finish systems, but tens of thousands of homes have been built without it, causing mold in vertical walls below an adjoining roof. Kick out flashing is also recommended around fireplaces and deck attachments. Breathable, thick wall materials, on the contrary, can handle this degree of water pressure, although kick out flashing is still a recommendation we support.

Improper Window Flashing, Window Maintenance and the Use of Caulks

Many builders would add several additional ways that rainwater enters wall cavities, including improperly installed flashing around windows and doors, lack of careful maintenance of paint and other finishes on windows, and the failure of caulk and other sealants. These are very common and preventable causes of mold growth in walls.

Rainwater intrusion from improperly installed flashing is remedied by careful attention to detail by the window installers. For example, flashing around windows and doors must be installed in the proper order so that rainwater flows down the drainage plane and stays outside the wall cavity. If flashing is layered in the wrong order, rainwater can run straight into the cavity. For an excellent discussion of how to do this properly, complete with detailed step-by-step diagrams, see the Energy and Environmental Building Association's *Builders Guide for Cold Climates*.[108].

Gene Eldeen, the remodeler and insulation specialist in Minnesota, has previously worked with a major window manufacturer on this issue. He recommends using fiberglass rather than metal for window cladding because if metal window cladding is dinged or hit by large hailstones, the entire length of it is disturbed and can separate from the exterior wall slightly at the caulking. That allows rainwater to seep in, rotting the wood window frame underneath and causing mold growth.

Fiberglass window cladding, on the other hand, is more flexible, meaning caulk stays intact if the cladding is disturbed. Also fiberglass outlasts metal, in Gene's opinion. He says metal and wood do not bond well together and therefore that combination of materials does not wear well. Silicone caulk also separates from glass, according to Eldeen, allowing slow water seepage, usually within two years. You will notice this by the fogging between the panes of glass in double pane windows. Polyurethane caulk used on glass, on the other hand, is more compatible with metal and will last up to 20 years. Finally, caulk that is hidden from the sun lasts much longer as the UV portion of sunlight cannot degrade the caulk as fast as when it is exposed.

[108] J. Lstiburek, *Builders Guide to Cold Climates*, pp. 244-252.

Eldeen goes on to say that sealants used behind metal window frame cladding fail over time and need to be replaced within about twelve years. He has seen this happen with all window manufacturers that use metal cladding over wood. When the caulk cracks and shrinks, water will get behind the wood and it will rot. Eldeen also advises leaving a gap at the bottom of the window to let out rainwater. He says, "Don't go tight" with windows.

Eldeen also says that if windows, and the rest of the house for that matter, are well maintained over the years (re-caulked and repainted), they will last without problems even when built with a wood frame and wood cladding. His thirty-year-old wood-framed windows are still in pristine condition, he says, because he has maintained them well.

Builders run into problems when they build houses with the notion that they are "maintenance-free," a growing trend these days. This leads to the use of materials that fail over time and allow water intrusion and mold. Eldeen says there is no such thing as "maintenance-free" construction. We agree with this sage advice and recommend that you use the natural, breathable materials in this manual, many of which are *relatively* maintenance-free (non-synthetic stucco, plaster), and that you maintain those materials that do need care over the years.

On the issue of caulk, the University of Massachusetts' Paul Fisette states that even though building codes approve its use as part of an accepted weather protection system, caulk is not able to keep up with the amount of expansion found in most siding at its joints and seams. He goes on to say that, "even if a joint doesn't move enough to make the caulk *itself* fail, in time, repetitive movement and prolonged exposure cause failure at the bonded connection." Furthermore, "A hairline crack is large enough to admit pressurized water, but not large enough to encourage drying. In the short term caulking can help block water penetration. In the long run it actually traps moisture behind the siding."[103] This alone is a reason to consider breathable materials to avoid the problem in the first place.

Additional Sources of Water Intrusion

Yet another cause of rainwater intrusion can occur with anchored brick veneer. According to Neil Carlson, where building codes require an air gap behind brick, masons often occlude this drainage space with mortar that extrudes too far behind the brick. Wind driven rain water enters the brick system primarily through the mortar joints and enters the drainage cavity behind it. Extruded mortar prevents water from draining down. Carlson has seen mold growth on the sheathing system as a result of this. Brick layers must be careful to maintain the openness of this drainage plane.

The University of Massachusetts' Paul Fisette brings up another issue, that of not waterproofing the underside of wood cladding. Moisture that penetrates wood cladding can be absorbed and stored by unfinished wood. This moisture is then absorbed by plastic house wrap and penetrates the wall cavity. Fisette explains that, "The sun's heat can turn the stored liquid water into vapor. The vapor moves inward when the temperature of the siding face is warmer than the air behind the siding. And since house wraps are vapor permeable, they can allow vapor to pass into the building envelope from the outside. As the sun sets or moves to another side of the house, the temperature of the wall may drop below the dew point temperature, changing the vapor back to liquid. And guess what? The reconstituted liquid is on the wrong side of a water-resistant barrier."[103] This is one of many reasons why we do not recommend plastic house wrap.

On another topic, whatever you do, do not power wash your siding! Doing so not only forces water under great pressure behind your siding, but also any surfactant used makes the water "wetter" by breaking down its surface tension. This allows the water to more easily penetrate what drainage plane you may have and enter the sheathing.

Failure of Sheathing Materials

Finally, let us discuss sheathing materials themselves relative to rainwater intrusion. Oriented strand board (OSB), plywood, and grayboard (buffalo board) are favorite sheathing materials. All have their own particular problems when they get wet from rainwater intrusion. Joseph Lstiburek states in his Builders Guide to Cold Climates that while OSB and plywood are normally impermeable to water vapor when dry, they become permeable to water vapor when they get wet, allowing structural damage and mold growth.[109]

Mycologists say that the glues used to hold the wood chips together in OSB make it a great food source on which mold can grow. They feel that virtually all modern pressed board building materials promote mold growth, primarily because of the glue content. Their list includes chipboard, OSB, buffalo board, all of which contain glue, and even the paper lining of sheetrock. These experts say they have seen exfoliation of OSB when the glues disintegrate from moisture intrusion and mold infestation. This leads to serious structural damage of the house and ill health for occupants.

The solution is not just to switch to paperless drywall. It is imperative to create an overall wall design that ensures water can dry out soon enough to avoid mold growth and structural damage yet maintain good insulating effect. Thick wall materials provide this automatically. For wood-frame construction, George recommends a comprehensive solution using breathable, affordable, waterproof and mold-resistant sheets as a replacement for wood sheathing in the support wall. These sheets are made with magnesium oxide and magnesium oxychloride. George also sprays a liquid mixture of magnesium oxide, kaolin clay and borate onto the wood studs and fills the cavity with cotton insulation. He completes the wall system by applying natural stucco to the outside of the magnesium oxychloride board with a single, thin, breathable layer of magnesium oxide and phosphate. Alternately, mineral-based paints and stuccos are highly recommended over magnesium oxide boards, especially on exterior applications. These materials and protocols are discussed in detail, along with thick envelope materials, in chapters 8 and 9.

[109] J. Lstiburek, *Builders Guide to Cold Climates*, p. 276.

7.7 The Capillarity of Plastic House Wrap

Plastic house wrap is designed to act as a one-way water resistive membrane, keeping liquid rainwater from entering a wall cavity from the outside while allowing water vapor to escape to the outside from within. That is, it is capillary-closed but vapor permeable. It is generally applied on the outside of the support wall sheathing and is intended in cold climates to allow moisture vapor that collects within the wall cavity, primarily during the heating season, to dry to the outside. House wrap is used as both a "water resistive membrane" and a "wind wash barrier."

However, as verified in an April 30, 2007 communication between the editor and DuPont, makers of Tyvek® brand house wrap (800-448-9835; construction.tyvek.com), there is actually no directionality to the permeability or capillarity of house wrap made of plastic. In fact, basic house wrap would also work as intended *even if the outside and inside faces were reversed* (i.e. the writing were inside)–as long as there are no grooves or other features that perform auxiliary functions such as assisting the migration of liquid water down the surface. (The weave of the fibers within the wrap is designed to do just that when wrap is installed with the letters right side up, according to Minnesota remodeler Brian Witte of Wit, Wood and Nails (952-220-4543; bwitte1@ msn.com). Doing the opposite, that is, installing the wrap so the letters are upside down, according to Witte, prevents water from easily draining down.) As described in section 6.3, water vapor diffuses in *both* directions in a permeable material such as plastic house wrap, depending upon the concentration gradient. Likewise, liquid water is stopped in either direction in such a material having low capillarity.

What is asymmetric in this application is that there is liquid on the outside in the form of rain water that needs to be kept out and water vapor on the inside that needs to get out. Modern walls are designed so that generally (though not always) there is no liquid on the inside nor vapor on the outside (see the exception described by Paul Fisette in the previous section). When liquid water does condense inside a wall, as described below, it cannot escape to the outside because the plastic house wrap keeps it from doing so, in the same way that house wrap doesn't allow liquid rain water to get in. This last point likely explains why building inspectors notice as much as two inches of standing water in some modern wall cavities.

According to Tim Dornisch, a siding contractor in Minnesota (952-930-0194; timdornisch@yahoo.com), plastic house wrap was first used in the 1980s as a wind barrier. Originally and as late as the mid-1990s, it was only used up to twelve inches from corners, with the rest of the exterior wall not covered. Beginning around 1999 or 2000, it began being lapped, taped and spread over the entire insulated portion of the house to serve as a waterproofer. The attic was never wrapped. In the past five years, however, house wrap has begun to be applied to the exterior of the entire house.

Ever since plastic house wrap has been used as a water resistive membrane, several problems have developed. The first is that builders and mold experts are finding that it fails as a moisture retarder when some types of siding are nailed directly against it. This is the capillary action discussed earlier regarding mechanisms of intrusion. Engineers explain that this occurs because the surface energy of the material is changed, allowing the capillary action.

Wind driven rain, which potentially can leak past most siding systems, can then move to wet substrate materials like the sheathing and wall framing members. In many homes the affordable choice for sheathing is impregnated fiberboard rather than more solid wood products. Fiberboard is commonly known as blackboard, grayboard, or buffaloboard. Moisture easily saturates this material and reaches the insulation within the wall cavity. Builders like the fact that fiberboard dries out so quickly when wet, but that can only happen if the drainage membrane does not inhibit the process. Once the rainwater penetrates all the way to the inside, it stays trapped long enough to promote mold growth. See below.

Plastic house wrap manufacturers, aware of this problem, are now marketing products with vertical corrugated grooves or ridges to allow a minute air gap behind the siding to promote water drainage. This is a step in the right direction. So-called "drainable" exterior insulation and finishing systems (EIFS) as well as grooved foam board panels are also now on the market. Some of these new systems are quite expensive, and according to Toolbase Services, they are new enough that certified installers are hard to find. Toolbase Services says that, "Drainable EIFS can cost between $4.50 and $7.50 per square foot, roughly $1.00 or more per square foot than retarder systems. By comparison, the installed cost of vinyl siding is about $1.50 to $4.00 per square foot."[110] (We, of course, do not recommend vinyl siding.)

Fortunately now, when wood frame buildings are built, many builders are switching back to building paper rather than plastic house wrap for their drainage plane. Sean Morrissey of Morr Construction Services in Arden Hills, Minnesota (651-633-0139; www.morrconstruction.com), builder of the first LEED for Homes dwellings in the state, reports that code inspectors are favoring the change to paper in an effort to create homes that are more breathable. To accomplish this, Sean says they want a waterproof drainage plane that allows vapor to work its way out. He also says that building inspectors are now being trained in the general concept of breathability. This is a very welcome development!

Michael Anschel of Otogawa-Anschel builders in Minneapolis (612-789-7070; www.otogawa-anschel.com) echoes Morrissey, saying that inspectors are being taught that building paper creates healthier, more breathable houses because water vapor is allowed to work its way out while rainwater is prevented from entering. Pat O'Malley, Director of Operations of the Building Knowledge Consulting Group in Minneapolis (952-444-5605; www.buildingknowledge.com), also agrees, saying he recommends builders "go the extra mile" by using two layers of grade D building paper plus a plastic mesh for an air gap rather than using plastic house wrap with cladding nailed right against it. We applaud this new direction in the thinking of builders and code officials alike.

Controversy still exists about which waterproofer to choose, in large part because of variability in testing methods. Paul Fisette states that the American Society of

[110]See http://www.toolbase.org/TechInventory/TechDetails.aspx?ContentDetailID=988&BucketID=6&CategoryID=54.

Testing and Materials (ASTM) recently published a report comparing the three most-used weather-resistive barriers, that is, plastic house wrap, building paper (also known as "felt paper") and asphalt-treated kraft paper. Their conclusion was that with the existing variability of testing methods and standards, they were unable to come to consensus on the topic. The chairman wrote, the three materials "are 'described by different...standards' and that 'there is no way to compare materials by a common set of criteria.'"[103]

In spite of this controversy, Fisette agrees with the builders and code inspectors that building paper (referred to here as "felt") is best. He states, "I believe that under certain circumstances, felt outperforms house wrap. For example, an ice dam or roof leak may allow liquid water to get behind the felt or house wrap. It's also possible for the sun's heat to drive water vapor through the house wrap from the outside, where it can condense on the sheathing. In either of these cases, you now have liquid water on the wrong side of the wrap. Under these conditions, the liquid water would be trapped by the house wrap, which is permeable only to water vapor. Felt, on the other hand, will absorb the water, and more quickly dry to the outside." [103]

While all of these steps are in the right direction, whenever homeowners and builders choose to build a house with a wood-frame construction, we favor the solution proposed by George, incorporating sheets of magnesium oxide sheathing over a wood frame sprayed with a mixture of magnesium oxide and clay, with cotton insulation filling the cavity. The other option, for those who can avail themselves of it, is to use breathable, thermally massive thick-wall materials for the entire envelope. Bear in mind that one of reasons the energy code requires a vapor barrier on the outside of walls is because the materials don't handle exposure to water very well. The thick wall materials presented in this manual don't have that problem. See chapter 8.

There is yet another way plastic house wrap can promote water buildup in walls. Architect and teacher Edward Allen explains[111] why the vapor retarder should be on the warm side in northern climates, i.e. just inside of the insulation and framing, which are covered by sheet rock. That is the standard of practice in construction today, but it assumes moisture that collects within the wall cavity on the cold side of the vapor retarder will exit through a semi-permeable layer of plastic house wrap that will forever allow moisture to escape. Yet this is not always the case.

The problem is that moisture-laden air that leaks through openings in the air flow retarder on the warm side of a wall cavity can deposit moisture in such quantities that it overwhelms the ability of house wrap to dissipate it to the outside. This leads to an accumulation of condensed liquid water and represents a potentially significant failure in the performance of plastic house wrap, according to George. He states that even though house wrap is designed to allow moisture to escape while preventing liquid rainwater from entering, the plastic may itself become impermeable over time. This is because the pores stop "breathing" and lose their permeability after fifteen to twenty years due to eventual fatigue of the plastic's "memory," according to George.

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[111] Edward Allen, *How Buildings Work*, Third Edition, Oxford University Press, 2005, pp. 68-69.

Even though some manufacturers have reformulated house wrap to prolong the plastic's memory and retain its permeability, George recommends against its use because it can still eventually seal in moisture over the years, reducing the wall cavity's ability to dry out when it becomes wet.

On the other hand, magnesium oxide boards used as sheathing or breathable thick wall materials do not need exterior plastic house wrap or building paper, because they absorb what little surface water is not shed by the exterior cladding. As a result, these materials have the capacity to release any moisture they absorb as either liquid or vapor within sufficient time to avoid mold growth and structural damage.

7.8 The Downsides of Fiberglass as an Insulator

Fiberglass, the old standard insulation infill, can perform poorly when you need it the most. According to George and other builders, an additional reason for the condensation of moisture in a wall cavity is that in a conventional wood frame house insulated with fiberglass, the fiberglass gradually turns into a conductor of cold in winter (or heat in summer), losing its insulating capacity.

Fiberglass performs poorly in the presence of relative humidity levels within a wall cavity higher than just 30%. As noted above, in winter this leads to condensation of moisture carried in by warm, vapor-containing indoor air that leaks into the wall through defects in the air retarder and raises humidity levels.

Once fiberglass becomes damp, the downward spiral accelerates because the thermal performance of fiberglass is worse when wet. One study reported in Ann Maurice's *House Doctor* book[112] states that a 1.5% increase in moisture content in fiberglass reduces its R-value by up to 50%. Furthermore, Paul Fisette states in his article cited previously[103] that "Leaking water rots wood, grows mold, corrodes steel *and lowers insulating R-values.*" [emphasis added].

Therefore, when moisture is trapped in a conventionally-built wall cavity sealed with a vapor retarder and insulated with fiberglass, the conditions are created for the insulation to become damp and lose its ability to insulate. This allows mold to grow and causes structural damage, defeating the purpose of using fiberglass as an insulator in the first place.

A second problem with fiberglass is its thermal performance at low temperatures, even when dry. According to Joel Hirshberg, proprietor of Green Building Supply in Fairfield, Iowa (www.greenbuildingsupply.com) and other sources, a little known fact about fiberglass is that it loses as much as 40% of its insulating capacity when outside temperatures fall below 20 ˚F. When that happens, Hirshberg says an R-19 fiberglass-insulated wall performs as if it were R-9. According to the Cellulose Insulation Manufacturers Association (888-881-2462; www.cellulose.org) thermography confirms this reduced thermal performance for fiberglass at low temperatures, particularly in windy conditions. In addition,

112 Available at www.housedoctor.co.uk.

Mike Holcomb, the regional certifier for the U.S. Green Building Council's LEED for Homes program (www.usgbc.org), quotes a Canadian cold weather study that showed that fiberglass loses half its R-value below 0 °F.

One possible cause of the failure of fiberglass as an insulator, according to Carl Seville of Seville Consulting in Atlanta, Georgia (www.sevilleconsulting.com), is that it acts better as a filter than as an insulator. He says that to act as an effective insulator, each fiberglass batt must be fully enclosed on all six sides as it lays within a wall cavity, without any air gap between the batt and adjoining studs. The face of the batt must also be in continuous contact with the air flow retarder. Fiberglass batts will only insulate when these conditions are met, according to Seville, but they rarely occur in the real world due to air infiltration through defects introduced in the air retarder during installation.

The third problem with poor thermal performance of fiberglass is demonstrated in studies conducted by the Canadian Wood Council (www.cwc.ca). They show a loss of insulating capacity of the portion of each fiberglass batt laying next to supporting wood studs within each cavity. This is because cold is conducted into the wall by the 2x4 or 2x6 stud through a phenomenon known as "thermal bridging." *[A footnote will be added later. –Ed.]*

We discuss alternative insulators to fiberglass in chapter 9. Our preference is to use cotton insulation in our wood framing protocol using magnesium oxide boards. Cotton behaves differently than fiberglass when wet in that it is able to dry more quickly. See sections 10.5.

The one application of fiberglass we are not as concerned about is laying fiberglass batts, preferably formaldehyde-free, in an attic floor and covering them with blown-in cellulose. Fiberglass in batts has a memory and expands if compressed. On the other hand, according to remodeler Gene Eldeen, if you walk on blown-in fiberglass (or cellulose, for that matter), it will never regain its loft. He therefore recommends laying fiberglass batts, which retain their loft better, on the attic floor, and covering them with blown-in insulation, such as cellulose, for additional loft. We would suggest cotton batts rather than fiberglass batts as your bottom layer.

7.9 Mold Growth from Wet Materials Stored on the Job Site

One final but important cause of mold in wall cavities occurs during the building process itself. This problem lurks even if you successfully manage to avoid all the difficulties mentioned above. Wood-based building materials stored on a construction site get wet from rainwater, even if covered. When these damp materials are installed in the framing of the house, they are often not given the time to dry before the frame is covered with plastic house wrap. This leads to the sealing in of both an abundance of moisture that fosters the growth of mold and any mold that may have already grown on the wood while it was stored outside.

Even if plastic house wrap has been installed over dry wood, which theoretically should keep everything dry, the wood frame and sheathing can easily become wet in a severe rain storm if the plastic wrap is torn by wind, letting rainwater pour in. How often have you driven by a job site during a rain storm and seen sheets of plastic house wrap flapping in the wind? Now moisture is allowed to enter the wall cavity, which is not allowed to dry before the walls are filled with insulation and sealed up from the inside with a plastic air retarder.

To make matters worse, toxic fungicides are now applied to building materials after rainwater intrusion to inhibit mold growth. They are also applied by manufacturers to wood products at the factory as a preventative measure. While this is an acknowledgement by industry that mold is a problem, in our opinion applying toxic fungicides is the wrong solution because of toxicity for occupants and workers. We instead recommend the use of materials that naturally do not become moldy when wet.

There is one bright spot on the horizon for those mainstream builders who choose wood-frame construction. They are turning to quaternary ammonium compounds such as the Modec Decontamination Formulation (MDF) series of products, also known as "Decon®" or "Precon®," manufactured by Modec, Inc. of Denver, Colorado (800-967-7887; www.deconsolutions.com). Precon® is applied to new wood framing during the construction process. This technology was developed under government contract and patented by Sandia National Laboratories.[113] The U.S. Army has used large amounts of this agent in Afghanistan and Iraq for its originally intended application, the neutralization of bioterrorism and chemical warfare agents such as anthrax or nerve gas. It was subsequently found by the Army's collaborators at Modec to kill mold *and* to chemically decompose mold's mycotoxins.

MDF® is stored in two parts: (A) a biodegradable mixture of cationic detergents and fatty alcohols (quaternary amine), and (B) 8% hydrogen peroxide. When mixed together on the job site and dispersed as a fog, the highly oxidizing combination kills mold spores on exposed surfaces. MDF® is toxic for a few hours during application, and proper precautions must be taken by certified workers. However, once applied, it harmlessly biodegrades within 60 days, according to Modec's Brian Kalamanka, leaving behind a nontoxic potassium bicarbonate film. Some builders are routinely fogging all of their newly framed houses with Precon before the wall cavities are insulated as part of their mold-prevention strategy. Chemically sensitive clients of Building Biology® Environmental Consultants are reportedly able to tolerate this product and it is supposed to be safe for pets and plants. Distributor Brian Fisher of Controlled Environment Solutions in Monticello, Minnesota (866-304-7529; www.cesdecon.com) reported to us on his first four years of experience with Precon. His customers, who are builders, and their clients have not seen any mold on exposed treated surfaces in the 20 homes to which the pretreatment has been applied. There have been many more widespread applications of the product in institutional settings such as nursing homes by a Tampa, Florida company called Innovative Decon Solutions (866-383-6653; www.idsint.com).

[113] The technology, referred to as the Sandia Decon Formulation, is detailed on the national laboratory's website: http://www.sandia.gov/SandiaDecon/. The specific application to construction pretreatment is described on the Modec, Inc. website at www.deconsolutions.com/Predecon.html , and references therein. Scott's Liquid Gold Mold Control 500, mentioned in section 18.2, uses basically the same formulation.

An alternative to Modec's MDF® is Sanifect-128®, part of a package usable by homeowners from the HAZARiD company of St. Paul, Minnesota (800-675-0323; www.hazarid.com).

If you do choose to build a wood frame house, George's protocol of spraying the wood studs with magnesium oxide and clay and using magnesium oxide boards for sheathing renders the wood studs waterproof and mold-resistant. Furthermore, breathable materials such as low-density fiber-cement wall forms will dry out after they are rained on while stored on the job site. Once installed in walls and foundations, the bare wall forms, minus their stucco layers, also dry out when rained on without any mold growth or damage to the material. No vapor retarder or plastic house wrap is needed because these materials fully dry out. (The base stucco coat of sand and cement provides an adequate air barrier that remains breathable for water vapor to pass.)

7.10 Comparing Conventional and Breathable Wall Systems

We have laid out in great detail the problems with modern construction techniques caused by water intrusion and condensation. Literally the entire building industry is trying to cope with this issue and come up with workable solutions, with only mixed results. Before we describe our approach in detail, let us first summarize the differences between conventional wall design and breathable, thick wall systems, particularly in cold and mixed temperature climates.

The ability of a wall cavity to dry to the outside, particularly in a cold climate during the heating season, demands that sheathing and exterior waterproofing materials be vapor semi-permeable. This can only happen if rigorous installation practices are followed and drying occurs within one to two days of moisture entering a wall. Drying in sufficient time does not always happen in modern walls and is severely hampered if wall cladding does not have an air gap and a drainage plane behind it. Either rainwater that enters from the outside or moisture that condenses from infiltrated indoor air can overwhelm the ability of plastic house wrap to allow the moisture to escape to the outside in sufficient time to prevent mold.

The classic wall design for cold climates also presents a problem during the cooling season, because then you want to prevent moisture from entering the wall from hot, humid outdoor air moving to the cool, drier inside. Defects occur in moisture retarders (plastic house wrap) on the exterior wall that normally allow the escape of moderate levels of moisture during the heating season. These external barriers need to be impermeable to the entry of moisture during the cooling season, but often they are not.[114]

Some builders try to get around this by simply acknowledging that moisture will gather in wall cavities over the summer, assuming that they will dry out when the

[114] J. Lstiburek, *Builder's Guide to Cold Climates.,* pp. 280-281.

heating season arrives some months later. This is unacceptable to us because we cannot recommend allowing a wall cavity filled with porous materials such as wood, spun glass fiber and wall board lined with paper to be wet for more than one to two days, let alone several months. The authors of this manual have opened wall and cathedral ceiling cavities that were filled with water that could literally be wrung out of the insulation by hand, moisture that had accumulated over months. In these cases mold was also present and the occupants were symptomatic.

To be successful the classic cold climate wall design relies upon maintaining mechanical control of air pressure and moisture both summer and winter. We have found it to be difficult for a typical family in the real world to manage the human contribution to moisture (showers, cooking, use of kitchen and bathroom exhaust fans).

Lastly and most importantly, even in the best of circumstances, building practices that successfully avoid condensation of moisture in wall cavities under normal conditions will unfortunately allow mold growth when the unexpected happens. Many builders concede that moisture will enter their walls in spite of efforts to keep it out. They know water intrusion events do happen.

One example is the case of indoor relative humidity levels exceeding the designed tolerance of a wall when occupants cannot change their living habits and use an exhaust fan. A second example is mechanical ventilation and dehumidification systems that break down or that shut down during a power failure. Another increasingly common example is flooding from extreme weather, which some say may be a more frequent occurrence as global warming and climate change worsens. The most common example, however, is improper installation of door and window flashing and the failure of caulking over time.

How well do conventional wall systems handle the unexpected? Not very well, as we have seen. From our standpoint, even a small amount of mold is unacceptable, and we therefore recommend wall systems that dry out in sufficient time. When you add the other benefits of breathable, thick-wall construction, the choice is well worth the increased cost up front. These benefits include low toxicity, a healthy indoor ion ratio, acoustic quietness, energy cost savings, steady and comfortable indoor temperatures, and durability.

With conventional building techniques, we do agree that if builders are able to meticulously follow the EEBA guidelines for their climate, they would have a better chance of protecting their wood-frame construction from water intrusion and mold, but many building crews are not able to be so careful. Then there is little room for error. As Joseph Lstiburek, the author of the EEBA guidelines, points out, what works in Las Vegas does not necessarily work in Seattle. Builders in the colder, sometimes wetter north often use practices suitable only for drier climates. Lstiburek also acknowledges that "the more moisture-sensitive the materials, the more rain control [is] required." Yet when water does enter these walls, they often do not dry out in time, with disastrous results.

There are many factors to consider when constructing a modern wood or steel frame wall using wallboard, batt insulation infill, sheathing and cladding. These include moisture vapor diffusion, flow of vapor-laden air, air pressure differentials, and interior humidity levels. If a builder does not carefully consider all factors and workers do not meticulously follow good technique, the wall cavity cannot respond to every condition to which it is exposed.

The problem is not just with the concepts underlying mainstream building practices, but also with their execution in the field. Today's building designs work in theory but not in practice. There is too much reliance on mechanical ventilation systems always working properly, on caulks and sealants lasting for decades, on air retarders always maintaining a proper air seal, just to name a few. Our solution is to use protocols that are much more forgiving and allow room for error.

As Building Biology® professionals we invite our readers to think outside the box and be willing to accept a paradigm that on the face of it goes against the common belief that if buildings are not watertight, they will fail. We believe, on the contrary, just the opposite is true. When attempts to keep water out fail in a modern house, the wall system fails in a big way. There is no room for error.

With our approaches there is room for unavoidable human error. Buildings constructed with the materials and methods that we recommend, if done properly, can tolerate and indeed encourage the passage of water in vapor form, without causing structural damage or mold. Plus it is much easier to accomplish proper construction using breathable, thick wall materials than with conventional techniques and materials. We promote envelope systems that are much more forgiving of defects, incorrect building practices, exposure to the elements over time, and natural and man-made water events such as hurricanes, flooding, roof leaks and interior water pipe leaks. Combining thick envelope materials with plaster finishes on the interior, thick wall inner partitions inside the building, and solid surface flooring creates a house that can withstand a major water event. Even if such an event happens it does not leave you with overwhelming damage or mold.

To put our approach in terms that building scientists can understand, Joseph Lstiburek calls breathable thick wall products "moisture insensitive materials with a high drying potential."[115] He calls a thick wall assembly a "storage/reservoir system, where some rain is permitted to enter and is stored in the mass of the wall assembly until drying occurs to either the exterior or interior."[116] Lstiburek says intelligent site planning, where a building is protected from prevailing winds and the design includes rain-protecting features such as roof overhangs and extended window sills, can go a long way toward reducing the wind-driven rainwater load that the exterior wall must handle. He says that when storage/reservoir systems have "designs with high drying potentials to the exterior, interior or, better still, to both" and are constructed properly, they "can be built anywhere."[117]

Furthermore, as described in chapter 6, there are substantial benefits from using our approaches, including healthy indoor air quality, steady ambient room air temperatures, healthy long-wave radiant heat and cool, acoustic quiet, durability,

[115] Ibid., p.229.
[116] Ibid., p. 230.
[117] Ibid., p. 231.

low maintenance, reduced energy costs, better health for your family, and higher resale value for your home. All of these features are side benefits when you invest in an envelope system that appropriately handles water vapor.

A home built the modern way, on the other hand, cannot provide all these benefits. To build such a house in a heating climate commits you to a plastic vapor retarder and plastic house wrap which worsen rather than solves the problem. Even if attempts are made to follow best practices described above, such as substituting building paper for plastic house wrap and providing an air gap and drainage plane, the results does not come close to the experience of homeowners who choose breathable, thick wall materials. Furthermore, the wood frame homeowner cannot expect his or her benefits to last over time.

Instead we recommend that you choose one of the breathable building systems presented in this manual, because all of these systems allow *slow* diffusion of air and water vapor right through the wall by the mechanisms discussed in the previous chapter. The best alternative in our opinion for cost-conscious homeowners who still want to build a wood-frame house is to use the protocol proposed by George in chapter 10, including magnesia-based sheeting, spraying of wood framing elements with magnesium oxide and clay, and infill insulation, such as cotton, that dries when it becomes wet.

We present more detailed information on how breathable, thick wall materials solve water intrusion issues as we discuss each of the options in the next chapter.

7.11 Conclusion

It is clear that the paradigms underlying modern building techniques work theoretically but not in the field. Homeowners, insurers, and members of the building trade throughout North America are now painfully aware of the problem. Indeed, the consensus among a growing number of forward-thinking builders and code inspectors is that current practices actually create the perfect conditions for mold to grow within walls. It has even come to the point that new homeowners need to seriously consider budgeting for the possibility that the true cost of their conventionally built home may be upwards of one and a half times the mortgage if rebuilding the walls becomes necessary due to water intrusion and mold.

One of the co-author’s clients in Minnesota had consulted Joseph Lstiburek a few years ago regarding an insulation problem in their cluster of buildings. Lstiburek told them that had he known in the beginning what he knew now about the problems with vapor retarders and tight building construction, he never would have encouraged builders to construct houses as tightly as they do. Now he is advising builders to take careful measures to control water intrusion and condensation while allowing walls to dry out and, as mentioned above, only recommends plastic vapor retarders in far northern climates. Yet vapor barriers are now ensconced in building code. Fortunately, a few builders are conceding that walls will become wet and are aware of the need to allow them to dry out once that happens. Unfortunately the majority of builders, especially those involved in large developments, are still not heeding his advice.

The ultimate problem is that it is not easy to reverse this thinking because the concept of tight buildings is now deeply rooted into building codes and, worse yet, into the mindset of builders and homeowners. This is vital from an energy efficiency standpoint, but using plastic retarders is not the solution. Even though the paradigm has proven to be faulty unless meticulous care is taken, builders still seem unwilling to deviate from it because they know of no better way to avoid water intrusion while providing adequate thermal performance. They are wary of assuming liability for something they are not familiar with, even when holding onto the old approaches itself leads to liability. They still strive to build an ever tighter house, hoping to avoid water intrusion and mold growth, but to no avail.

Efforts to avoid the problem of mold growth by sealing up houses are fraught with too many opportunities for failure. As we have stressed in this chapter, when contemporary walls fail, the consequences are hard to overcome. Shesh Aandahl says that “Mother Nature always wins.” We could not agree more with her.

We offer a more foolproof method of design and construction that acknowledges the inevitable intrusion of moisture and allows walls to “breathe” and dry out. We recommend that our readers consider joining the growing number of homeowners and builders who are adopting these approaches, practiced successfully for centuries in Europe.

In the next chapter we discuss our recommended materials in detail.

Chapter 8. Breathable Envelope Materials

8.1 Introduction

Prior to the Industrial Age, traditional building methods utilized natural materials close to the construction site. Homes were crafted by the owner or by local craftsmen. There was no mass production, indeed there was hardly a building industry. Steve Servais, historian and principal of Pragmatic Construction in Milwaukee, observed that "As shelter is a basic component of survival, one could say that home construction is as old as humanity itself. Often using locally available resources, humans around the globe devised perhaps thousands of unique ways of achieving the same end—providing a barrier between themselves and the outside world of rain, wind, sun, and often enemies. From thatched mud huts to stone villas, a home often reflected the culture of its society, the environment in which it stood, and even the individual personality of its builder."[118]

To satisfy the building biological criteria set forth in chapter 6, our building materials must be permeable, hygroscopic, and have the desired degree of capillarity. We call these characteristics breathability. Moreover the materials should ideally have a high thermal mass and be progressively more insulating towards the outside of the wall, providing what we call "out"sulation. Clearly the structure should be strong and stable enough to bear weight indefinitely. Lastly we prefer walls constructed from primarily natural materials, as they alone provide the full range of desired properties as well as health-promoting subtle energies, without outgassing

Arguably in an ideal world every dwelling would be meticulously hand-crafted with locally available natural materials that satisfy our criteria, with little regard for the cost of labor. In recent years, beginning in the 1960's and 1970's with the back-to-nature movement, there has been a revival of these time-honored building techniques. But what was taken for granted is now considered as "alternative." Therefore these methods tend to be used by mavericks, artisans, and free spirits who build a very small number of homes. Doing it the old-fashioned way may be highly satisfying to builder and owner. Unfortunately the labor-intensive methods and the absence of standardized materials mean that a conventional modern contractor finds it difficult if not impossible to economically build using these age-old techniques. This is changing, however, as more and more builders jump on the "green" and sustainable band wagon, seeking materials to stay competitive in the marketplace, which itself is going green. As you will see, there are several manufacturers who use traditional materials to produce modern building products that satisfy our criteria for health, sustainability and thermal performance.

[118] Steve Servais' essay, "A Few Thoughts on the History of Home Construction," was posted on his company's website: http://pragmaticconstruction.com/History.pdf (last accessed November 2007; broken link when checked in April 2008).

With the caveat that there are dozens of books on "natural building" methods whose wisdom we will not try to reproduce or augment, we start this chapter by briefly describing just a few traditional construction materials and techniques, such as earth, straw and clay. We include them because these traditions fulfill all the requirements for a home compatible with Building Biology®. With a lot of effort and determination, a small number of specialists in the industry may find a niche by using these traditional materials. More significant, we think, for the majority of builders and people considering building, is the fact that some of the raw materials have been integrated into the modern composite materials described later in this chapter. Moreover a few entrepreneurs are always working to develop more "practical" technologies based on traditional materials. Therefore we organized this materials-based chapter such that the detailed section on each composite material is preceded by briefer sections on its component raw materials. To some extent we have also taken chronology into consideration in determining when to discuss each material.

For at least 9,000 years *earth* has been used for construction by humans, and it remains one of the most popular building materials in the developing world. Some of the variations are wattle-and-daub, rammed earth, compressed earth blocks, adobe, and cob. Recently, earth-based technologies that can be mechanized and potentially practiced on a wider scale have been developed. *Clay*, a variable fraction but sometimes major component of earth, is a remarkable, finely divided substance that has earned its place as a valuable material with numerous physical and healing properties. Clay is the essential binding ingredient in any earthen building system and is an ingredient in modern composite building materials.

Straw was initially used as in a bird's nest to reinforce earth, improve workability and prevent it from cracking. Much more recently, bales of straw have been stacked to make massive walls. Later in the chapter we will describe advanced building materials made from other plant-based products such as hemp hurds.

Straw-clay construction is a post-World War II improvement on wattle and daub which takes advantage of the insulating properties of straw.

The lion's share of this chapter is devoted to more widely economical methods of construction that are still based upon time-tested traditional building materials, but are made by companies that use modern manufacturing techniques and have a proven track record in the field, backed by industry-accepted structural testing and code approval. We offer them here in the hope that those readers in the building industry will join their colleagues who already use them in this and other countries and will fully embrace them over time. The methods used to build with these materials will be expanded upon later, beginning in chapter 9.

Wood is the first of our recommended materials to be covered and represents a transition from old to practical. Of course log homes were popularized by the American pioneers but they have been around for at least two thousand years. In the last 40 years an industry has risen to manufacture these structures. An alternative but time-tested method is timber frame construction, in which large timbers are used as the major structural support in a post-and-beam configuration. A lesser-known method called cordwood construction is used by some adventurous do-it-yourselfers. Wood chip is also a key component of fiber-cement composites and of "wood wool" panels popular in Europe.

Cement in the form of concrete is a significant component of most modern buildings, primarily as a slab and foundation material. In the middle of the 1800's Portland cement took over from traditional, magnesium oxide and lime-based cementitious materials. Unlike these traditional cements, Portland cement is *not* a breathable material so the reader will immediately wonder why it belongs in a chapter on breathable envelope materials. For a number of reasons we feel that its inclusion is merited, despite some significant health and global environmental concerns. Portland cement provides the structural skeleton of some breathable composite materials. Portland cement also imparts an alkaline environment to the wall form, disallowing mold to grow. The health concerns pertaining to the use of Portland cement are mitigated by combining it with the right materials. Furthermore, in order to be fully load-bearing, some breathable wall form systems do require structural reinforcement with concrete and rebar.

Autoclaved aerated concrete is a less energy-intensive and breathable Portland cement-based material that has been available for seventy-five years. AAC is made by a unique process that incorporates air bubbles, air being the best insulator, such that the product has a density of only about twenty percent that of ordinary concrete.

Low-density fiber-cement wall form, based on mineralized wood chips and Portland cement, has a proven track record of over half a century and is one of our preferred wall systems. The mineral coating on the wood chips consists of either clay or a ceramic material that neutralizes the sugars naturally present in wood that would otherwise render it incompatible with Portland cement. Generally the stacked wall forms are filled with Portland cement and rebar, allowing buildings to be many stories high.

Traditional or "alternative" cements, in most cases formulated with magnesium oxide and chloride or phosphate-containing minerals, are seeing a renaissance which we fully endorse, for these materials solve the many problems associated with Portland cement. Magnesium oxide, as we will see, was the world's first cement, and it has seen an explosive revival in recent decades, particularly in Southeast Asia. It is now receiving attention in North America. This chapter describes an impressive array of related building products.

For example, two entrepreneurs in Iowa have revived a formula based on magnesium oxychloride, hemp and rice hulls to create a solid building envelope based upon techniques used for over 600 years in France. Their low-density fiber-cement product is a solid block containing no hollow core and no Portland cement.

Magnesia-based sheeting products have recently become available in North America, following the lead of the Chinese building industry, where over 900 factories now make building boards for domestic use and for export. Plans are underway to have these products made in the U.S. and Mexico for the North American market. In thick-wall construction these products are suitable for floors, walls and ceilings. For homeowners and builders not prepared to use cement-bonded wall forms or AAC to construct massive envelopes, using these sheets to replace drywall and plywood or OSB sheathing makes possible and affordable a breathable, mold-resistant wood-frame structure.

Lastly, we will take a brief look at some well-established breathable building technologies that are only available in Europe or other countries. We are hopeful that these will become available soon in North America.

In fact, many of the materials and methods recommended in this chapter are already in wide use in Europe, where occupants enjoy a significantly higher level of health and comfort than their North American counterparts. We in this country are often trapped in unhealthy and uncomfortable building envelopes, particularly since the widespread introduction of plastic vapor retarders after the oil embargo in 1973.

8.2 Earth and Clay

[We are sorry but this section needs to be totally rewritten and is omitted in this draft release of the book. –Ed.]

8.3 Straw and Other Plant Fibers

[We are sorry but this section needs to be totally rewritten and is omitted in this draft release of the book. –Ed.]

8.4 Straw-Clay

[We are sorry but this section needs to be totally rewritten and is omitted in this draft release of the book. –Ed.]

8.5 Wood

[We are sorry but this section needs to be totally rewritten and is omitted in this draft release of the book. –Ed.]

8.6 Concrete Made with Portland Cement

[Unfortunately we have found it necessary to completely rewrite this section and the best we can do for you now is to provide the following outline of what we intend to say. –Ed.]

1. <u>History</u>
    a. Mention briefly general history of cement
    b. In the middle of the 1800's Portland cement took over from

traditional, magnesium oxide and lime-based and other cementitious materials

c. Firmly entrenched now in the building industry

2. Portland cement (PC) is n*ot* "breathable", so why is it included in this chapter?

    a. It serves a major structural function in its own right, as a foundation and slab material

        i. It has virtues of high strength (albeit inferior to some alternative cements), high thermal mass, and low cost (albeit heavily subsidized)

        ii. Cement in the form of concrete is a significant component of most modern buildings, including many artisan-crafted homes that feature envelope materials already described in previous sections of this chapter

    b. It is a component of composite materials that we highly recommend, described later in this chapter, and also an additive in some earthen composites

        i. Low-density fiber-cement, made from PC (section 8.8)

            1. Portland cement provides the structural skeleton of some breathable composite materials.

            2. (Note bonding problems as described under Properties, 3.i.)

            3. Portland cement also imparts an alkaline environment to the composite material, disallowing mold to grow.

            4. The health concerns pertaining to the use of Portland cement are mitigated by combining it with the right materials.

    c. Structural reinforcement of envelopes constructed from other materials

        i. In order to be fully load-bearing, some breathable wall form systems do require structural reinforcement with concrete and rebar.

    d. Component of other systems we do not recommend, such as conventional ICFs (expanded polystyrene)

3. Properties (refer to whatever pertinent data is given in the tables in chapter 6 and other references, such as Adam M. Neville's *Properties of Concrete*.)

    a. High strength (as just mentioned in 2.a.i.)

        i. of concrete itself

        ii. of reinforced concrete (rebar)

    b. High thermal mass (as just mentioned in 2.a.i.)

        i. Cite new white paper from the UK

c. Upon formation contains large stores of free water that are difficult to release due to capillary limitations
    i. Large masses of concrete are exceedingly slow to dry out, for concrete starts out as a completely liquid-saturated material as a result of its formation by mixing in water
    ii. Modern polymer additives, when used to make "enhanced" concrete, further clog the pores, making it even harder for concrete to dry out.
d. Extremely hydrophilic but capillary water absorption is not readily reversible due to tendency to be saturated
e. High surface area (experimental data)
f. Somewhat hygroscopic (see J. Straube's data, indicating an increase from 2 wt. % at 50% RH to 3.5 wt. % at 85% RH) despite expected decrease in surface hydroxyl groups (–OH) from high-temperature firing
g. Water vapor permeance is just over 2 perms, on the low end of the "semi-permeable" range, similar to the value of wood, but only after it is fully dried out.
    i. Mention a bit about the microstructure, from pp. 31-32 of Neville's book as well as our own examination of one sample, to be discussed later in this chapter.
h. Highly electrically conductive due to high absorbed water content
    i. Will drain an older, rubber-encased car battery (an illustration only) and possibly withdraw electrons from surrounding living organisms
i. Bonding is difficult between PC and other materials (unlike in traditional cements)
    i. you must have a bonding agent present in the cement mix to enable the cellulose of wood forms to adhere to the cement
    ii. you need to neutralize its sugars and acids before binding wood to concrete, as in fiber-cement composites

4. <u>Mold</u>
    a. As explained at length in chapter 7, mold easily forms on other, mold-prone materials in areas of buildings surrounded by concrete that dries too slowly, e.g. in basements, due to high humidity from either
        i. water used in initial concrete curing, which often takes months or years to dry out
        ii. water intrusion or plumbing leaks that don't dry out in the required 1-2 days
    b. Mold-related illness is rampant among residents of homes built with conventional wood-frame construction, and the use of Portland cement in the foundations and slabs contributes to these health effects.

c. (As we shall see in the following sections of this chapter, this effect is mitigated when PC concrete is integrated into composites containing breathable materials such as low-density fiber-cement, allowing the composite material to readily dry out.)

5. <u>Health effects</u>

   a. *Early observations:* Building biologists in Germany observed and reported wide-ranging adverse health effects ("Betonkrankheit"="concrete sickness"=fatigue, etc.) in people who lived and/or worked in buildings or wartime bunkers constructed of PC, even in the absence of mold formation

      i. During formation of clinker at extremely high temperatures, PC releases naturally present waters of mineral crystalline hydration. Hubert Palm, the physician often credited with founding Building Biology®, believed that this would destroy the "life qualities" (life force or subtle energies) of the crystals, making them responsible for the observed concrete sickness. He cites Paracelsus.

      ii. Palm also postulated that concrete interfered with beneficial earth and cosmic radiation.

      iii. Palm also recognized that concrete reinforcement with steel, if present, has two adverse effects on health: (1) interfering with the naturally present electromagnetic fields and radiation that man has evolved to live in; and (2) amplifying any effects of the building's electrical system.

      iv. Radioactivity is on occasion a serious problem.

   b. The precise mechanism for such symptoms as fatigue in workers is not known but has been speculated by others to possibly involve the draining of electrons from organic material, such as the human body, pets or the cellulose in plants, standing on or near floors and walls built with Portland cement. (A car battery drains its charge in an analogous fashion.)*Recent Observations*

      i. Modern experts in "stray voltage" effects on cows in dairy buildings have observed and reported quantifiable decreases in milk production and adverse animal health and behavior that, while attributable to electrical currents from grounding of the AC electrical service (and best remedied by trying to reduce these currents), are worst when concrete floors are newer ("new barn syndrome"), containing a higher moisture content and having greater electrical conductivity. In the absence of any other remedy, problems attributed to "stray voltage" decrease as the concrete ages and dries out. (However problems do not go away without more directly addressing the problem.)

   c. *Remedies to the Problem:*

      i. Palm envisioned "bio-cement" and "bio-concrete" made of natural materials, with intact waters of hydration due to lower processing temperatures. Later in this chapter (section

8.9) we will describe precisely these alternatives.

ii. The German government has apparently regulated the amount of time that factory workers can spend on concrete floors (mention alternative materials in other sections of chapter).

iii. As described in section 8.8, German employers have reportedly made cut outs in the concrete floor beneath assembly lines and replaced them with cork-covered cement-bonded wood fiber board over direct earth for workers to stand on.

iv. George's alternative slab protocol is explained in chapter 11.

1. Adding a sub-slab layer of vapor permeable low-density fiber-cement chips.
2. Covering the slab with a layer of magnesium oxide

6. Environmental problems
    a. Concrete production uses immense amounts of energy and is responsible for a major fraction of the CO_2 emissions impacting global climate change
    b. Much of this energy expenditure is subsidized by the public, e.g. Alcoa story
    c. In many buildings today, fifty to ninety percent by weight of a wall or foundation made of solid concrete serves no function other than holding up its own "dead weight." Substituting other materials or making composites can avoid this waste of resources.
    d. Toxic additives may release VOCs
7. Solutions
    a. Solutions to at least some of the above problems are offered later in this chapter
    b. Cost is becoming less of an issue as these developments progress.

8.7 Autoclaved Aerated Concrete (AAC)

Autoclaved Aerated Concrete (AAC), also known as the "Hebel" block, is a solid masonry product used around the world in all climatic conditions, from the humid African continent to Finland in Northern Europe. Structures built in Europe over 75 years ago are still in use today. It has been used in the Far and Middle East for the past 40 years, and in Australia and South America for the past 20 years. AAC has been manufactured here in the United States since the mid 1990's.[119] AAC is a complete building system comprised of blocks used for wall and foundation construction as well as pre-cast wall, floor and ceiling panels.

[119] See http://www.aacpa.org/faq/index.htm#1.

Figure 12. Home built with AAC. (Photo courtesy of SafeCrete.)

AAC is comprised of traditional Portland cement and lime, which is foamed with aluminum metal and aerated to create millions of air cells. As a result, the panels are lightweight and provide high thermal performance. Steam autoclaving of the blocks during their manufacture provides strength. Rebar is used but only at the corners and around openings, such as doors and windows.

Figure 13. Lightweight AAC block. (Photo courtesy of SafeCrete.)

AAC is durable, affordable, easy to work with, mold- and termite-resistant, non-combustible, fire-rated, acoustically quiet, and environmentally safe because it does not outgas. The blocks should not, however, be used below a water table as they have high capillarity and do not resist osmosis.[120]

For a sample of AAC provided by SafeCrete, we have measured the density, internal surface area and pore size distribution (shown below in Figure 14) and observed the very interesting microstructure by scanning electron microscopy. These results do confirm the low density and are consistent with reports of a high degree of vapor permeability and capillarity for AAC. The results also show a predominance of pores within the microstructure that are sufficiently large in

[120] An Irish builder, Viking House (www.viking-house.ie), made this point in a web page on AAC last accessed in January 2008 but no longer online.

diameter (i.e., greater than 0.05 microns) to allow rapid diffusion of water vapor molecules through the material. From these data one should expect to measure high vapor permeance values for AAC.

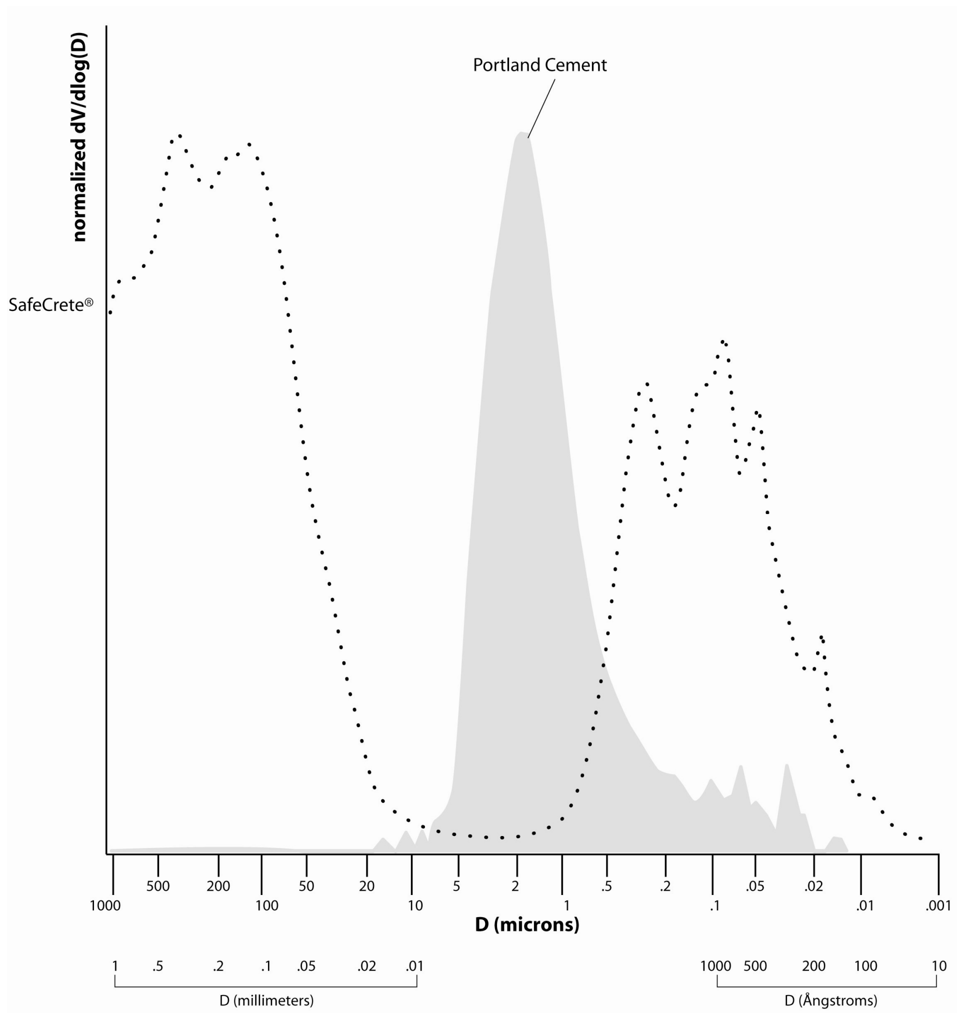

Figure 14. Pore size distribution, dV/log(D) versus D (where V=volume and D=-diameter), for SafeCrete® autoclaved aerated concrete (dotted line), as compared to cured Portland cement without aggregate (grey shaded area). Measurements were performed by the Quantachrome Corporation using a mercury porosimeter.

Recall that in section 6.5, we discussed the fact that free-draining materials have pores or voids exceeding the maximum pore size for capillary absorption to keep moisture from being trapped in homogeneous materials. Unlike the passage of water vapor, capillary absorption or desorption of liquid water requires pores significantly larger than ten microns, the minimum size of a droplet, so we direct your attention to the left-hand side of the plot, which by convention displays the larger diameters at that end of the logarithmic x-axis.

It should be readily apparent in Figure 14 that in AAC there is a big population of very large pores having diameters greater than 100 microns—this is consistent with the open cell configuration of AAC, which can be accurately described as a very capillary-open material.

It is also evident from Figure 14 that there are not only very large pores present, there are substantial numbers of what we will call "superpores" that are significantly larger than the experimental cutoff diameter of one millimeter. Just how much larger we don't know, but it is possible that some of these are large enough to form a capillary break, facilitating drainage of liquid water from the material and speeding the drying process. We will see similar findings when we discuss the porosity of magnesium oxide boards below.

George adds that the AAC product made by different manufacturers may potentially have different pore sizes in their blocks. He suggests a good at home test of capillarity is to put a small one-inch by one-inch by four-inch section of block in water and measure how fast water raises. In general, the AAC block has much more capillary action than low-density fiber-cement wall forms, and you would therefore expect the water to be taken up by the block sample. He says there is little or no movement of water when the same test is done with either Faswall® or Durisol® brand low-density fiber-cement wall forms. We discuss this issue in more detail below.

AAC provides proven cost savings for builders during construction, and for homeowners due to lower life cycle costs, lowered by as much as half compared to conventionally built homes.[121] As a result, AAC, like other materials in this manual, is estimated to pay for itself within several years, making it affordable in the long run compared to wood frame construction.[122]

AAC provides the "time lag" properties for building owners inherent with thick wall construction, shifting cooling loads to nighttime hours in the cooling season when HVAC equipment needs to work less and electricity costs are often lower for commercial building owners. This shifts peak electricity loads to non-peak hours so you "compete against the average temperature of the day, rather than the peak temperature," according to the website of one of the manufacturers.[121]

As we discussed previously, laboratory tests of the thermal performance of AAC block showed that temperatures measured on the inside of an AAC wall maintained a steady range within 2 ˚F at the same time that outdoor temperatures varied by as much as 126 ˚F. AAC is able to accomplish this because of the insulating capacity of millions of trapped air cells that slow the ingress of heat into the wall. Heat from the summer sun normally takes an hour to travel only one inch through AAC block.

While light in weight, AAC behaves like other, more massive wall materials, due to the presence of air cells. AAC achieves this light weight by the aerating of concrete: "The end product is approximately 80% entrained air and 20% mass. Thus 5 parts AAC are produced from just 1 part raw material, making the product very resource-efficient."[122] Likewise, far less energy is used in the manufacturing of AAC than traditional concrete materials, making AAC an environmentally safe product.[122]

[121] See http://www.safecrete.com/aac/benefits/energyeff.cfm.
[122] See http://www.safecrete.com/aac/faq.cfm.

How does the embodied energy of AAC compare to that of Portland cement? According to a reference[123] cited by the Illinois State Geological Survey, "In addition to saving energy through its insulating properties, the manufacture of AAC requires less energy than other building materials. AAC requires two thirds less energy to produce than brick and at least half the energy required to produce concrete or porous bricks (Hums 1992)."[124]

Thick wall properties create different dynamics within an AAC wall when compared to traditional wood frame and batt insulation construction, allowing it to insulate as well as traditionally constructed walls. As a result, "the insulating abilities of an 8" (AAC) wall performs like R-30 insulation."[122] While this is impressive, builders in Wisconsin have noted that this may be insufficient in the extremely cold climate of the northern United States, however the product is reported to be used in Finland and is sold in Rhode Island. Other builders, including Viking House in Dublin, Ireland, recommend rockwool slab insulation or "wood wool" insulation boards externally when using AAC in northern climates[125] (although these products are unavailable in the United States).

In this country AAC finds its main use in southern states where most of the manufacturing plants are located and predominantly cooling environments prevail. It has excellent thermal performance in that type of climate. There are, however, suppliers in northern states (see below).

AAC blocks are assembled on the job site with thin-set mortar. Air infiltration is prevented because the walls are made with single components, and there is no thermal bridging, thus adding to superior thermal performance. Traditionally constructed wood frame homes, as previously noted, lose heat through bridging from inside to outside at every stud and lintel.

We discuss the use of AAC on the job site in section 9.5.

Like other thick wall materials, AAC walls are hygroscopic and therefore have virtually no chance of trapping moisture and developing mold (provided the walls are not encased in non-breathable finishes and barriers). According to the E-Crete website,[122]

> Why is a vapor barrier not required in the exterior wall assembly of E-Crete AAC wall?
>
> The enclosed cellular structure of E-Crete along with the exterior finishes provides the healthy balance between resistance to moisture penetration and vapor diffusion. This balance maintains a dry system, prevents moisture condensation and allows vapor diffusion when and if any presence of vapor occurs within the wall system.

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[123] Hums, D, "Ecological aspects for the production and use of autoclaved aerated concrete," in *Advances in Autoclaved Aerated Concrete*, F. H. Wittmann, ed.: Lisse, The Netherlands, Balkema, pp. 43-50 (1992).
[124] See http://www.isgs.uiuc.edu/isgshome/assets/acc_block_flyer.pdf.
[125] See http://www.viking-house.net/aac-blocks.

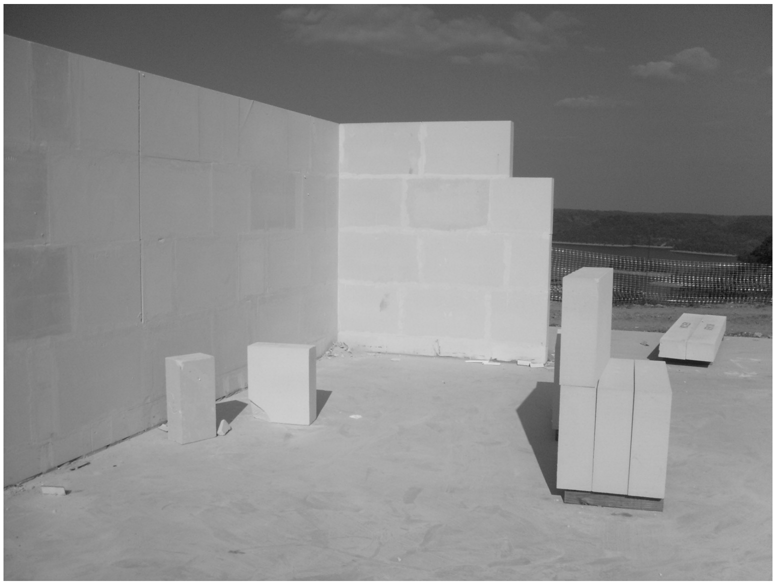

Figure 15. AAC wall panels. (Photo courtesy of SafeCrete.)

AAC blocks also allow some degree of natural fresh air exchange. Cool, air-conditioned air moves slowly from indoors to outdoors in summer through such a "breathable" wall, taking eight to ten hours to pass and warming slowly as it moves out. Likewise warm outside air cools as it slowly nears the inside wall surface. This causes no significant loss of indoor cooling energy yet contributes a small degree of fresh air exchange with the outdoors.

To further demonstrate this point, studies at the Oak Ridge National Laboratory showed that air infiltration in AAC walls, a source of heat loss, was "63% less than a wood stud framed structure and 48% less than an un-insulated 8 inch CMU [concrete masonry unit] wall."[126] AAC houses are therefore more "airtight" than conventional wood frame houses, even with vapor barriers, while allowing stale air and water vapor to pass through very slowly without loss of thermal performance.

According to the same report:

> The results of computer simulations for the six U.S. climates show that annual energy performance of the single family residence made of AAC walls is superior in comparison with a similar house built using either two-core CMU, steel studs, or conventional wood-framed walls. AAC wall yielded the least operating energy cost when compared with other wall systems.

The white paper quoted above thoroughly documents the thermal conductivity, thermal mass and low air-infiltration properties of AAC block. (It should be

[126] "Thermal Performance for AAC Block, Residential Application," presented by the Autoclaved Aerated Concrete Products Association (AACPA) on the website of one of their members, http://www.e-crete.com/pdf/03-thermal_properties.pdf.

noted that AAC was not tested against low-density fiber-cement wall forms, such as Durisol® or Faswall®.)

One of the great advantages of AAC from our standpoint is its ability to provide superior indoor air quality:

> "AAC products are an excellent choice for the chemically sensitive because autoclaved aerated concrete does not offgas. AAC does not promote the growth of mildew and mold, and cannot be infested by termites. Rats and other pests find no home, since there is no cavity in an AAC wall. Pesticides can be reduced, and the occupants can breathe a little easier."[122]

One builder, Gregory Vine of Venice, Florida, has used AAC blocks in several homes in his environmentally sensitive, affordable subdivisions, according to an article published by Environmental Building News.[127] Vine reported greatly increased comfort levels and significantly lower energy costs for the AAC homes, compared with their concrete-block counterparts.

One must consider the issue of fly ash. Many building biologists do not support the use of fly ash due to its heavy metal content. Inquire of the AAC manufacturer you contact whether they use fly ash, and if so, ask if they make an AAC block without it. Some manufacturers use sand as an alternative to fly ash.

One other potential drawback, mentioned above, is the issue of how AAC handles water uptake when siding or stucco is not properly installed. George has built over one dozen AAC block houses and considers the capillarity to be the greatest downside of this product. He says if the stucco is not done correctly, especially near grade with rain backsplash, the water uptake issues of the block can be significant. Faswall® and Durisol® solve this issue far better, in his opinion. He concludes that building with AAC is vastly superior to conventional framing, but when it comes to water issues, it is not as good as Faswall® or Durisol®.

AAC is made in over two hundred production facilities worldwide under such names as Hebel and Ytong. It is manufactured in several locations in the USA:

- SafeCrete, Ringold, Georgia (706-965-4587; www.safecrete.com)
- Aercon Florida, Haines City, Florida (863-422-6360; www.aerconfl.com)
- True Stone America, also known as E-Crete, Tempe, Arizona and Providence, Rhode Island (877-351-4448; www.e-crete.com)
- Texas Contec, San Antonio, Texas (877-926-6832; www.texascontec.com)
- Flexcrete (www.flexcrete.com) – a British company with US distributors

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[127] "Autoclaved Aerated Concrete: Is North America Finally Ready?" *Environmental Building News*, Volume 5, No. 2, March/April 1996. Available at http://www.buildinggreen.com/products/aaconcrete.cfm.

Suppliers of AAC can be also found in Georgia, Texas, Wisconsin, Illinois, New York, Maryland and Hawaii. Go to the website for the Autoclaved Concrete Producers Association (http://www.aacpa.org/directory/index.htm) for a directory of members and non-suppliers (their designation for installers and resellers of the product).

AAC is another ecologically sound, nontoxic, healthy alternative to standard wood frame construction. For additional information on this product, go to the following websites:

> http://www.toolbase.org/Technology-Inventory/Foundations/autoclaved-aerated-concrete
>
> http://www.cement.org/basics/concreteproducts_acc.asp
>
> http://www.treehugger.com/files/2006/11/concrete_can_it_1.php ("Concrete: Can it be Green") [Their answer is no, without considering AAC.]
>
> http://www.architectureweek.com/2006/0222/environment_1-1.html ("Saving Concrete Energy" by Michael Cockram.) [PC production releases 8% of worldwide CO2 emissions.]

8.8 Low-Density Fiber-Cement, Made with Portland Cement

The manufactured envelope material most widely recommended by the Building Biology® profession in North America is made by combining plant fiber with a cementitious binder. Although the time-honored binder for low-density fiber-cement has been magnesium oxide, clay or lime, in the modern era it has been Portland cement. This fiber-cement combination provides all the desired properties that our profession looks for in a building envelope material.

The plant fiber/cement combination can be used to make a variety of building envelope products that include structural panels and modular stay-in-place forms for building concrete structures. The premier product is the lightweight, low-density cement-bonded wood fiber wall form, representing the original insulating concrete form, or ICF, system. These forms most exemplify the qualities we feel are important in an envelope system.

What follows is a detailed discussion of the history, composition, manufacturing processes and properties of the two low-density fiber-cement products based on Portland cement that are presently on the market in North America. A third low-density fiber-cement product, based on plant fibers and cement derived from magnesium oxide, is described later in the chapter. (See section 8.10.)

History and Current Use

Building with low-density cement-bonded fiber materials has been occurring throughout the world for centuries. These practices may have naturally evolved from the "wattle and daub" and straw-clay construction methods mentioned earlier in this chapter. Ancient Mexico employed these building techniques over

800 years ago with examples still in existence. For example, there is a monastery made from this material near Monterrey, Mexico that is over 190 years old. Portions of this building that George personally worked on are still standing today and have no rainwater leakage or mold growth.

The modern building envelope product made from this material uses wood as the fiber material and Portland cement as the binder. The woodchip-cement composite material is created at a factory and molded into the shape of hollow "wall forms" that resemble conventional masonry blocks. The interlocking wall forms are dry-stacked on site and completely filled with concrete and reinforcing steel. (As discussed in chapter 9, our preference is non-metallic rebar to reduce potential exposure to electric and magnetic fields.)

The originators of the modern technology of breathable, thermally-insulating, cement-bonded wood fiber wall systems were likely inspired by traditional straw-clay construction (see section 8.4) and motivated to streamline it. However this became feasible only once some problems had been resolved. In particular, as mentioned in the last section, Portland cement does not readily bond to materials containing cellulose, because the water-soluble sugars and acidic compounds naturally present within the pores of the plant fibers interfere with or "poison" the cement curing process. In spite of this difficulty, the fabrication of fiber-cement building materials, from the combination of by-products of the wood-processing industry with inorganic raw materials, was already taking place in the middle of the nineteenth century, according to a student review paper posted on a German architectural website.[128] The products, referred to as "Steinholz" (woodstone), "Sägemehlbeton" (sawdust-concrete) or "Holzbeton" (wood-concrete), were reportedly used for a range of applications, but particularly as floor screeds and plasters.

However the efforts to unite wood *chips* with cement did not actually begin until the 1920s, as per a recent German doctoral dissertation[129] that cites as its source an article in a trade industry publication.[130] For those to whom these publications are not accessible, the patent literature[131] of the 1920s documents the state of the art, which allowed only relatively dense wood fiber-cement composite materials to be made. For example, one British patent, granted in 1927 to James Rankin

[128] Oliver Alex and Karsten Boermann, "Holzbeton", student paper for Prof. Dr.-Ing. Thomas Jürges' course in Structural Design (2005); available (in German) at http://www.archinoah.de/files/studienarbeiten/20060124holzbeton_1.pdf.

[129] Roland Krippner, "Untersuchungen zu Einsatzmöglichkeiten von Holzleichtbeton im Bereich von Gebäudefassaden" (Investigations of the Application of Wood-Lightweight-Concrete in Outer Wall Constructions), Dr.-Ing. thesis, Technical University of Munich, Faculty of Architecture (March 8, 2004); available on a link from http://tumb1.biblio.tu-muenchen.de/publ/diss/ar/2004/krippner.html.

[130] Erich Beraus, "Holzspanbeton. Naturbaustoff – ökologisch und wirtschaftlich" (Woodchip-concrete. Natural building materiall – ecological and economical), *Beton + Fertigteil Jahrbuch*, pp. 103-109, Wiesbaden (2001). [Until recently the author was president of the Austrian firm, Durisol Werke GesMBH.]

[131] The reader can search the European Patent Office's international database on the Internet at http://ep.espacenet.com and retrieve complete patent documents, including those of the United States, Canada and Great Britain.

Garrow,[132] points out the problem with the influence of temperature and humidity variations on the strength and durability of products made in that era, which tended to easily warp and deform. Garrow's invention was to fill the pores of the wood fibers by precipitating a mineral or salt from a hot aqueous solution. Unfortunately this approach later turned out not to be economical due to the required heat and rather prolonged drying period.

Subsequently, in 1932, as outlined on the "milestones" page[133] of the Austrian website of today's leader in the industry, Durisol Werke GesMBH, Richard Handl announced the "breakthrough" in Holland that made possible the manufacture of lightweight, low-density composite products derived from Portland cement and mineralized wood chips. Handl and coworkers were granted a patent for this technology early the following year.[134] After further improving the process and exploring various options, as explained in patent applications dated 1937,[135,136,137] Handl sold all rights to industrialist August Schnell and architect Alexander Bosshard, who created Durisol AG in Switzerland in 1938. The Swiss firm entered an active product development phase, and their initial patent for a wall forming system was filed in 1948.[138] A patent applied for in 1947[139] demonstrates their continued research and efforts to improve the quality of mineralization and cement-fiber bonding as well as the ease of molding objects. (For more details see the following subsection.

Durisol AG was prepared for expansion precisely when the European continent needed to be rebuilt following World War II. Virgin lumber was scarce but waste wood was plentiful, and manufacturers sprang up making use of this abundant resource at a time when funds were scarce for using new materials.

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[132] James Rankin Garrow, Great Britain Patent No. 278,788: "Improvements relating to the preparation of organic materials or aggregates for use with cements." Application filed July 7, 1926; granted October 7, 1927.

[133] See http://www.durisol.at/seiten/01_unternehmen/02_meilensteine.asp.

[134] Richard Handl, Jacobus, and Johannes Meuzelaar, French Patent No. 739,965: "Procédé pour la fabrication de pierres et de plaques légères à partir de matières contenant de la cellulose et du ciment" (Process for the manufacture of stones and lightweight plates starting with matter containing cellulose and cement). Application filed July 13, 1932; granted January 19, 1933.

[135] Richard Handl and Wilhelm Fritz Wagner, French Patent No. 843,851: "Procédé pour la fabrication de matériaux légers et poreux par des matières contenant de la cellulose et du ciment ou mortier" (Process for the manufacture of light and porous materials from matter containing cellulose and cement or mortar). Application filed September 25, 1937; granted July 12, 1939.

[136] Richard Handl and Wilhelm Fritz Wagner, Great Britain Patent No. 519,547: "Process for the manufacture of light and porous materials from natural cellulose fibres and cement or mortar." Application filed in Belgium, September 25, 1937; granted March 29, 1940.

[137] Theodore Oswald Godin, Sr., Theodore Oswald Godin, Jr. and Richard Handl, Great Britain Patent No. 487,989: "Process for the manufacture of building materials." Application filed in Italy, January 22, 1937; granted June 29, 1938.

[138] August Schnell and Alexander Bosshard, United States Patent No. 2,805,567: "Hollow Block Wall Construction." Application filed November 6, 1948; granted September 10, 1957.

[139] August Schnell and Alexander Bosshard, United States Patent No. 2,592,345: "Method for producing lightweight concrete." Application filed August 25, 1947; granted April 8, 1952.

Shortly after the war Durisol AG awarded licenses to fifteen different enterprises that began making low-density fiber-cement, both in western Europe and abroad.[133] In the same era a Soviet firm, Арболит (Arbolit), independently developed similar wall form technology for the East bloc.[128,140] While the worldwide operations licensed by Durisol AG continued to expand in the 1950s and 1960s (see more about the company in the following subsection, Manufacturers and Licensors), some competing ventures arose, most successfully in Austria where low-density fiber-cement remains a very popular building material.[141] It appears that solid growth and geographic spread of the industry has continued into the 21st century.

As described in the next subsection, Durisol arrived in Canada in 1953 bringing its wall form technology to builders throughout North America. Later, after initially working with Durisol, a pair of Swiss immigrants introduced the Faswall® brand cement-bonded wood fiber form to the U.S. in 1984.

Durisol® has successfully penetrated the building market in Canada, and has consistently seen high growth in the United States, particularly over the past 5 years. Since the mid 1970s Durisol has sold over 3 million square feet of wall form product and over 20 million square feet of combined Durisol products, including wall forms, noise barriers and retaining walls. In 2006 alone, over 2.5 million square feet of Durisol product was sold in the United States. This still represents a relatively small portion of the building envelope market and raises the question as to why low-density fiber-cement construction is not yet widely used in America. One school of thought is that the price of lumber in this country is heavily subsidized. In Germany, where forest industry subsidies reportedly do not exist, a single 8-foot long 2×4 inch wood stud can cost upwards of $30. Consequently, in Europe companies like Durisol can provide superior products at competitive prices and flourish. There are currently 8 Durisol licenses in Europe manufacturing wall forms and producing over 8 million square feet of wall form product per year.

Faswall® has been available for residential and commercial construction in this country for over 20 years. But only a relatively small number of forward-thinking builders and homeowners have been introduced to cement-bonded wood fiber wall forms. With the growing movement towards green products and building techniques, builders are now taking a second look at this product. The new Faswall® licensee, ShelterWorks Ltd. in Corvallis, Oregon, has been shipping product for residential construction only since July 2007, but as of this writing they report “a high level of interest and exceptional growth” during the initial five months.

Contractors in America are already familiar with a denser cement-bonded wood fiber exterior siding product also called “fiber-cement,” but most frequently referred to by one of the manufacturer’s brand names, Hardiboard®. Hardiboard® is made from cellulose (which may be newsprint or sawdust),

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[140] The history of Arbolit was described on a Russian web page last accessed in October 2007, http://www.arbolit.com/faq.htm. (Unfortunately that site is no longer online.)

[141] A list of Austrian companies is given on www.holzbeton.com , the website of an Austrian industry trade association, the Arbeitskreis Naturbaustoffe-Holz-Mantelbeton (Working group of natural building materials-woodchip-concrete).

Portland cement, sand and inorganic fillers. This relatively high-density (1100-1400 kg/m^3) product is manufactured using processes similar to those used to cement together wood waste in the 1920s. Hardiboard is a useful siding option and can be applied right over a cement-bonded wood fiber wall with a stucco parge coat underneath, a step we recommend as the breathable weather shield. (See chapter 7.)

Other commonly used building products that incorporate fiber and cement are Wonderboard® and Durock®, which when applied behind ceramic tile, allow drying to take place when exposed to moisture. This helps prevent the development of mold in areas where moisture is prevalent, such as behind a sink or shower stall.

Manufacturers and Licensors

Cement-bonded wood fiber wall forms are manufactured worldwide and are used in both commercial and residential applications. They are made or licensed in North America by the following two firms:

1. Durisol Building Systems of Hamilton, Ontario, Canada (905-521-0999; www.durisolbuild.com), which markets their wall form product under the name Durisol®. The name and intellectual property are jointly owned by Durisol Resource Inc. of Canada and its two corporate partners in Austria and Holland that operate worldwide under the umbrella of "Durisol International Corp."

2. K-X Faswall International Corporation of Windsor, South Carolina (803-642-8142; www.faswall.com), which was started by Hans and Leni Walter, originally of Switzerland, who previously started Insul Holz-Beton International, Inc. (IHBi) in 1987 and K-X Industries in 1995 as a marketing arm for IHBi. Currently ShelterWorks Ltd. of Corvallis, Oregon (541-929-8010; www.shelterworksonline.com) is the only company licensed by the Walters to manufacture Faswall® in North America.

Durisol Building Systems Inc.

We already presented in the previous subsection some of the early history of the enterprise in Switzerland, at that time called Durisol AG, which started licensing their technology worldwide in the late 1940s. Canadian operations began in 1953, and today Durisol Resource Inc. of Canada is one of three international partners operating under the authority of Durisol International Corp., an Ontario corporation formed in 1990 which purchased all rights associated with the low-density fiber-cement technology from the Swiss company. Durisol Resource Inc. controls licensing rights for the Americas and Pacific Rim, but its licensees maintain and own their manufacturing facilities. The other worldwide partners include Durisol Raalte BV of Holland (www.durisol.nl) and Durisol-Werke

GmbH of Austria (www.durisol.at), which together operate throughout greater Europe, including Russia and the Baltic states.[142]

The licensees of Durisol International Corp. and Durisol Resource Inc. make fiber-cement-based materials for use as noise barriers, retaining walls and building wall forms. The company's first product, the insulating concrete forming system (ICF), was followed by the floor form, roof panel system and noise barrier system. Millions of square feet of each product have been installed over the past fifty-five years. Durisol has hundreds of different mold forms and can make custom forms. The Canadian business unit that manufactures and markets wall forms has primarily served the commercial building market in Canada for five decades, including load-bearing twenty-five story office and hotel buildings, parking garages and highway systems. After less actively pursuing the residential market for many years, Durisol Building Systems[143] is now more fully going after the residential market in Canada and the U.S. Their wall form product is used in the construction of over a thousand new homes a year in the province of Ontario alone, and builders in this country, who have been using the product steadily over the years, are beginning to take interest in a larger way.

The Durisol wall form is typically 12" high and either 24" or 36" long. The wall form sizes were selected to maximize the wall surface area without making the units excessively heavy. Each block is approximately the same weight as a masonry unit while covering between 2-3 times the amount of wall area that is covered by a conventional masonry block.

Durisol Building Systems obtained ICC (International Code Council) recognition in 1997, which was reissued in June of 2002. The Legacy Report is number ER-5472.[144] Their ICC recognition helps in obtaining code approval with local code officials when homeowners and builders choose the Durisol® wall form. Durisol is also working with ICC to modify their report and allow for multi-story commercial construction within the US and expect to have this in place in 2008.

Durisol was responsible for bringing cement-bonded wood fiber wall forms to North America and they are and always have been the largest manufacturer in North America. Durisol has conducted over fifty years of detailed research and development with many universities and testing agencies.

K-X Faswall International Corporation and ShelterWorks Ltd.

Hans and Leni Walter, who had used Durisol® in their native Switzerland and Florida, founded Insul Holz-Beton International, Inc. (IHBi) in South Carolina in

[142] The rather complicated company structure is explained at http://www.durisol.com/p1about.htm. (This is the website of another Canadian licensee, Durisol Inc. See note 143.)

[143] Durisol Building Systems should not to be confused with Durisol Inc. (www.durisol.com), another Hamilton, Ontario-based licensee of Durisol Resource Inc. that manufactures and markets their noise barriers and retaining walls which are principally used in road construction projects.

[144] See the report at http://www.icc-es.org/reports/pdf_files/UBC/5472.pdf.

1986[145,146] to market the Faswall® Concrete System. The name Insul Holz-Beton translates from German as "insulating wood-concrete," according to a January 2000 article by Ken Roseboro.[147] In 2000 the Walters merged K-X Industries and IHBi into K-X Faswall International Corporation.[148]

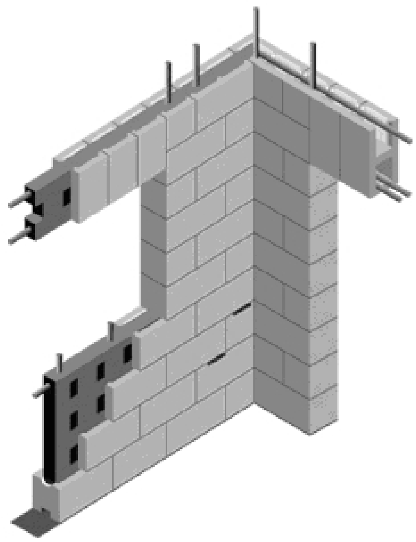

Figure 16. Structure of wall built with Durisol® wall forms. (Photo courtesy of Durisol Building Systems Inc.)

While Durisol's pioneers had already developed ways to bond the cellulose of softwood to Portland cement as far back as the 1930s and 1940s and had advanced the process to include other forms of cellulose, such as hardwood, in the following decades, the Walters likewise used an approach to bond Portland cement to wood, compatible with recycled hardwoods as well as softwoods.[149,150] Like the process used by Durisol, the resulting formula, which the Walters named the K-X Aggregate, allows mineralized wood to replace gravel in a concrete mix.[147] The processes of combining wood fiber with cement that are used by the two manufacturers are discussed further in the next subsection.

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145 "Checking in with Faswall," *Environmental Building News*, March 1998, Volume 7, Number 3. Available to members of BuildingGreen Suite at http://www.buildinggreen.com/auth/article.cfm?fileName=070308a.xml.

146 Email correspondence from Hans Walter to Oram Miller, June 4, 2007.

147 Ken Roseboro, "New chips on the block," *Concrete Products*, January 1, 2000, http://concreteproducts.com/mag/concrete_new_chips_block/.

148 Coincidentally, in 1989 a totally unrelated venture called KX Industries, L.P. was started in Connecticut using the same name as the Walters' IHBI subsidiary, minus the hyphen. This firm still exists, producing activated carbon filters for water treatment.

149 Leni M. Walter-Gurzeler and Hansruedi Walter, United States Patent No. 5,019,170: "Coated free aggregate usable in wood concrete technology and method of making the same." Application filed September 13, 1989; granted May 28, 1991.

150 Hansruedi Walter and Leni M. Walter-Gurzeler, United States Patent No. 5,314,744: "Double coated free aggregate usable in wood concrete technology and method of making the same." Application filed November 13, 1991; granted May 24, 1994.

The Walters developed a smaller, lighter wall form that could also be cast with a regular concrete block machine. IHBi licensed its process in succession over the next two decades to companies using facilities in Arkansas, Iowa and South Carolina. Although at least one of these operations produced a good product, all of the businesses failed within a few years for a variety of reasons.

The new and only remaining licensee is ShelterWorks of Corvallis, Oregon, where Thomas Van Denend, according to a June 2007 correspondence from Hans Walter,[151] "has put together a state of the art plant in the last 5 months in Oregon, and is now in production. They will deliver product throughout the US, with emphasis on the West Coast up to the Canadian Territories, and we hope this very well thought out and organized plant will spawn others throughout the USA—finally!"

Figure 17. Faswall® wall form. (Photo courtesy of ShelterWorks Ltd.)

See section 9.4 and chapter 15 to learn about the experiences of actual contractors throughout the country who have built with Durisol® and Faswall® wall forms.

Composition and Manufacturing Process

Turning to the composition of the original insulating concrete forming, or ICF, system, cement-bonded wood fiber wall forms are generally comprised of a mixture of chipped mineralized wood and Portland cement. In the case of Durisol® the relative proportions in the wall form mix are specifically 85% wood and 15% cement by volume as was reported in an email correspondence with one of the authors. By weight the numbers are reversed, i.e. the denser concrete

[151] Hans Walter email to Oram Miller, June 4, 2007.

makes up about 67% of the mix and wood makes up only about 33%.[152] (Of course these numbers do not include the cement poured into the core.) Over the years K-X Faswall International Corp. has also reported an 85/15 wood/cement ratio by volume,[153] but we were informed recently by ShelterWorks' that they go by the relative weight rather than the volume of the components in their version of the Faswall® manufacturing process. Therefore the 85/15 figure may not be applicable to their current process. ShelterWorks' weight ratio in the mix is about 62% cement to 38% wood, considerably lower than Durisol's. This allows them to obtain a Faswall® product having similar density to Durisol® (see next subsection) even though they are using denser wood.

However we were told by a Durisol Building Systems engineer that if the cement to wood ratio gets too low the modulus of mechanical rupture decreases significantly, leading to problems with blowouts when filling the wall forms with concrete, though of course the more wood is present the lower is the density of the wall form and the better it performs as thermal insulation. The engineer explained that "It is a bit of a balance to maintain cement to wood ratios and ensure adequate coverage of cement on the wood particles"[152] to achieve strong bonding while achieving good thermal performance and minimizing cement usage.

One source of the wood used in these wall forms is derived from mill ends and other types of softwood lumbar used in the making of wood trusses. These mill ends that would otherwise go to landfill are harvested by the wall form manufacturers and chipped into processed wood chips. Durisol uses exclusively these softwood mill ends in its North American operations, while ShelterWorks, the current maker of Faswall®, uses only wood from recycled pallets (primarily hardwood) and what they term "urban wood." See below for more discussion of the wood sources used by the two companies.

The wood chips in Portland cement-bonded wood fiber wall forms are mixed with the cement through proprietary processes to neutralize sugars, tannins, oils and resins in the pores of the cellulose. Otherwise the cement would not easily bond to the wood, causing rot and decay when the composite material is exposed to moisture. As a result of successfully bonding to Portland cement, the surface of the wood becomes essentially petrified and the wood fiber is hermetically sealed inside such that it does not rot, become moldy, nor can it be used as a food source by termites. The highly alkaline nature of Portland cement in these products further hinders mold growth.

[152] Durisol Building Systems representative, email correspondence to Wayne Federer, November 29, 2007.
[153] See http://www.faswall.com/tech.html.

Figure 18. Durisol® wall form. (Photo courtesy of Durisol Building Systems Inc.)

The two North American manufacturers of Portland cement-bonded wood fiber wall forms use proprietary methods to bond cement to wood fiber and render the latter inert. As mentioned just above in History and Current Use, beginning in the late 1930's the Swiss founders of Durisol improved upon a process developed by a Dutch inventor, resulting in a nontoxic finished product. After working with Durisol, Hans and Leni Walter began using a clay mineral process for bonding cement to wood in 1987[145,149,150]

Durisol Building Systems describes the bonding of cement to wood on the company website as follows:

> Mineralization is the proprietary process by which we remove the sugars from the wood and render the material completely inert, and no longer susceptible to rot or termite damage. The wood then becomes an inorganic aggregate similar to stone aggregate in concrete. *[This statement refers to the interfacial layer at the surface of the wood. Presumably the interior of the wood fibers is unaltered.[154] –Ed.] Durisol* is also known as "wood-concrete." It is the mineralization process that allows the cement to hydrate or 'strengthen' in the presence of wood particles.[155]

The final Durisol® product is free of toxic chemicals (as verified by the company's chain-of-custody documentation of the raw materials) and is said to contain only cement and wood fiber when it leaves the factory. The wall forms do not outgas as do walls and foundations made with concrete or materials containing petroleum-based adhesives, such as oriented strand board (OSB). The company's Technical and Installation Guide has a detailed table showing the low

[154] Durisol Building Systems representative, personal communication with Wayne Federer, November 21, 2007.
[155] See http://www.durisolbuild.com/F%20Wood%20Treatment.shtml.

degree of Total Volatile Organic Compounds (TVOCs) and formaldehyde emitted by Durisol® wall forms in Off-Gas Test Results.[156] Durisol® brand wall forms are therefore tolerated by the chemically sensitive homeowner.

As mentioned earlier, the two manufacturers of cement-bonded wood fiber wall forms use different wood sources. The Durisol process itself can use any type of cellulose material, including softwood, hardwood, or rice husk. Over the past 50 years, they have established the methodology to mineralize any of these types of materials and combine them with Portland cement. The choice of which wood source to use is dependent upon the following three factors:

- The type of material that is available near each facility
- The desired material properties for a given product.
- The more desired wood source as determined by the customer.

All Durisol noise barrier and panel type products (other products made by the company) use wood shavings only. These planar shavings are obtained from softwood lumber mills within the area. This material provides slightly higher NRC (Noise absorption) ratings in the final product.

All wall form and building products are made from processed wood chips (“Prochips”). This wood source allows the company to make a stronger wall form. The wood comes from truss manufacturers and is composed of softwood lumber pieces that are left over when the trusses are cut to shape. These pieces would otherwise be destined for the landfill. Durisol does not use other wood sources whatsoever.

Durisol also recycles existing wall forms from construction sites that are broken, etc. and grinds them to be used in new wall forms. This “post-consumer” waste refers to the Durisol material itself.

Durisol has further clarified that they do not use hardwoods primarily because they make the wall forms unnecessarily heavier. More importantly, they use clean waste lumber (the majority of which is softwood) to ensure that there’s no question regarding the potential for toxic chemicals having been stored on hard wood pallets, etc. The company can then confidently address their customers’ concerns about potential exposure to toxic materials and chemical sensitivities.

The manufacturers of Faswall® have had a different philosophy than Durisol regarding their wood source. Rather than using the mill ends that have almost certainly never been near any toxic chemicals, in the 1980s Hans and Leni Walter wanted to expand the use of wood materials in their product to include more plentiful recycled waste wood from pallets as well agricultural products.[157] The Faswall® process now used at ShelterWorks Ltd. utilizes exclusively wood from recycled pallets, consisting of approximately 75% hardwood and 25% softwood.[177] The purity of the product relies on the pallet wood supplier’s ability to and diligence in weeding out pallets that are obviously chemically

[156] See http://www.durisolbuild.com/Webdocs/Tech%20Guide%20(Photos).pdf , p. 3.
[157] Leni Walter, email correspondence to Wayne Federer, March 24, 2006.

contaminated.[158] It is on this basis, without the benefit of chemical analysis or chain-of-custody documentation on their wood source, that the licensor states on their website[159] that Faswall® wall forms contain no toxic chemicals, do not outgas, and are "the building system of choice for chemically sensitive people." However despite this less than perfect guarantee we have never heard of a single instance where a person could not tolerate the wall material in a home built with Faswall®. As pointed out by ShelterWorks' Thomas Van Denend, the Faswall® process has the benefit of "upcycling" a relatively low-grade wood source, and he told us that they cultivate a culture of quality among their raw material suppliers to reduce this risk.[158]

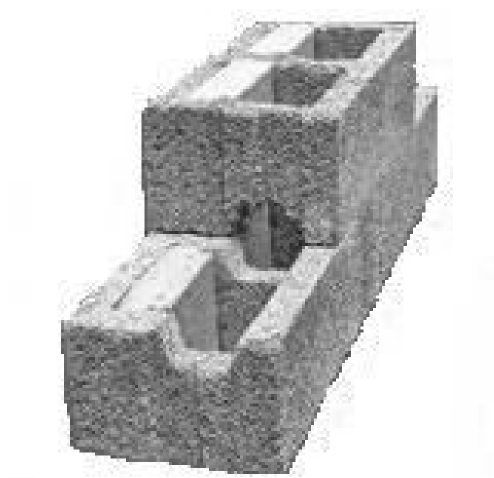

Figure 19. Faswall® wall forms. (Photo courtesy of ShelterWorks Ltd.)

Another process consideration affecting the "wholesomeness" of low-density fiber-cement forms is whether coal fly ash is used in manufacturing the wall forms. ShelterWorks is committed to lowering the embodied energy of their product and their management views fly ash as a positive step in that direction. Incorporation of fly ash also decreases the density of the wall form by a few percent. However ShelterWorks also recognizes the potential for heavy metal contamination, particularly when the wall forms are cut. As of this writing they do not use any fly ash but they are planning to offer customers a choice beginning in 2008 and will provide analytical data to document the degree of contamination.[160] Building biologists generally recommend against the use of fly ash unless the possibility of exposure to the toxins can be ruled out. The same issue is applicable to the production of autoclaved aerated concrete. (See section 8.7.)

Durisol does not use fly ash in any of its products for a number of reasons, including but not limited to potential toxicity.

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158 Thomas Van Denend, personal communication with Wayne Federer, November 21, 2007.

159 See www.faswall.com/benefits.html.

160 Thomas Van Denend, personal communication with Wayne Federer, November 26, 2007.

Some Physical Properties

We will begin this subsection with a disclaimer. Overall there is a lot more documentation of physical properties available for the Durisol® wall form than for Faswall®, although new licensee ShelterWorks' Thomas Van Denend has told us recently they have plans to augment their testing on Faswall® in 2008 using third parties, including engaging with the Wood Products Engineering department at neighboring Oregon State University.[158]

Although we have for convenience chosen to include both Durisol® and Faswall® in the same discussion, we want to emphasize that it is inappropriate for one to extrapolate from the properties of one manufacturer's product to another. There are a host of process and raw material variables, including the wood type and source, its preparation and moisture content; the chemicals and their concentrations used for mineralization; the wood-cement and water-cement ratios; any additives to the cement (for example, ShelterWorks will be incorporating fly ash into some of their product); and finally, the curing conditions. An example of this variability, a Durisol engineer pointed out to us that only a one percent change in the wood-cement ratio can make a major difference in the properties of resulting material.

Dimensions and Tolerances. The Durisol® wall form measures 24 or 36 inches long and from six to fourteen inches wide, depending upon the intended use. The height is 12 inches. See Thermal Performance below for a discussion of the various thicknesses. The smaller Faswall® wall forms made by ShelterWorks are all currently 24 inches long, twelve inches wide and eight inches high. Both companies make special forms for use in corners and around windows and doors.

The dimensional tolerances associated with the manufacturing process are an important practical consideration, as any large variations from wall form to wall form force the builder to be creative, using shims or other tricks of the trade to end up with flat wall surfaces. ShelterWorks reports a precision of ± 1/16 inch in their 12-inch wall form width[160] and states that their forms are trimmed at the factory within a tolerance of 1/16 inch.[161] Durisol, which makes larger forms that may require even more sophisticated process control to achieve dimensional precision, also report tolerances within ± 1/16 inch.

Density. According to the Material Properties document on the company's website,[162] the Durisol® wall form material is lightweight, with a dry density (oven-dried) of only 500 to 600 kg/m^3 (equivalent to 31 to 38 pounds per cubic foot). They also list a significantly higher range of 680 to 800 kg/m^3 for the "saturated" density, corresponding to the material equilibrated in a moist environment of unspecified relative humidity. This substantial increase over the value found for the dry state is consistent with the strongly hygroscopic character of Durisol®. The latter was already documented in chapter 6 and will be explored again below in the subsection on Breathability.

[161] Faswall® Technical Manual, version 2.1, obtained from ShelterWorks Ltd.
[162] See http://www.durisolbuild.com/Webdocs/Durisol%20Material%20Properties.pdf.

Faswall's current North American licensee, ShelterWorks, provided us[163] with a dry density specification of 33 to 35 pounds per cubic foot, which converts to 530 to 560 kg/m^3. This range is right in the middle of that specified by Durisol, which is at first glance a bit surprising because hardwoods are denser than softwoods. Van Denend attributes ShelterWorks' ability to keep the density down to their lower cement/wood weight percent ratio (see Composition and Manufacturing Process) above.

Porosity and Related Properties. Both of the lightweight wood chip-concrete composite materials are also highly porous. Durisol lists a porosity of 0.5 to 0.6, equivalent to 50 to 60 percent void volume. Upon the editor's request, the Quantachrome Corporation in Boynton Beach, Florida graciously analyzed samples of materials provided by Durisol's Vipul Acharya and K-X Faswall's Leni Walter, along with a disc of cured Portland cement mix without aggregate. From the results of Quantachrome's mercury intrusion analyses and the known density values, we calculated somewhat smaller but still substantial porosities of 0.37 for Faswall® and 0.34 to 0.40 for Durisol®. What this means is that about forty percent of the jacket volume of a low-density fiber-cement wall form made by either manufacturer is normally occupied by insulating air, which helps to explain the outstanding thermal properties (see later subsection) of these materials.[164]

Quantachrome's mercury intrusion analyses also revealed the distributions (histograms) of pore size for each sample. As displayed in Figure 20, Durisol® and Faswall® appear noticeably different from each other, but let's note first what is similar between the two. Quite unlike Portland cement, for which the very largest pore diameter is only 5 or 10 microns, both of our breathable wall form materials have major populations of extremely large-diameter "superpores," ranging from 100 to greater than 1000 microns or micrometers (0.1 to > 1 millimeters). Pores in this size range are sometimes called *capillary pores* because they are sufficiently large to allow capillary movement of water. However our mercury intrusion data only hint at whether or not this will actually take place because they only go as high as one millimeter pore diameter. As explained in the discussion of capillary absorption/desorption in section 6.5, a material will break all capillary forces and freely drain water if the largest pores are too big for the surface tension of the liquid to bridge the gap. That requires pore diameters of a few millimeters. Consistent with our pore size data, which show no evidence of a drop-off in the large peak centered near 500 microns (0.5 mm) and a likelihood of significantly large pores, Durisol® is reported by the company to be free-draining, supported by actual test data that produced a Darcy coefficient of 10^{-9}-10^{-10} kg/m·s·Pa.[162] Our data for Faswall® are less clear cut, with a lower intensity peak tailing off at the 1 mm limit of the graph, although all indications from the field are that Faswall® behaves likewise.

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[163] Tom Van Denend, personal communication with Wayne Federer, November 27, 2007.

[164] We were somewhat surprised to also find a large porosity, 0.7, for the concrete disc we prepared from Portland cement mix. However the samples were heated for 48 hours at 212 °F immediately prior to the measurements to render them completely dry. Under realistic conditions a large fraction of the pore volume of concrete is filled with liquid water remaining from the curing process, not air. This moisture has a very adverse effect on the material's thermal performance and other properties.

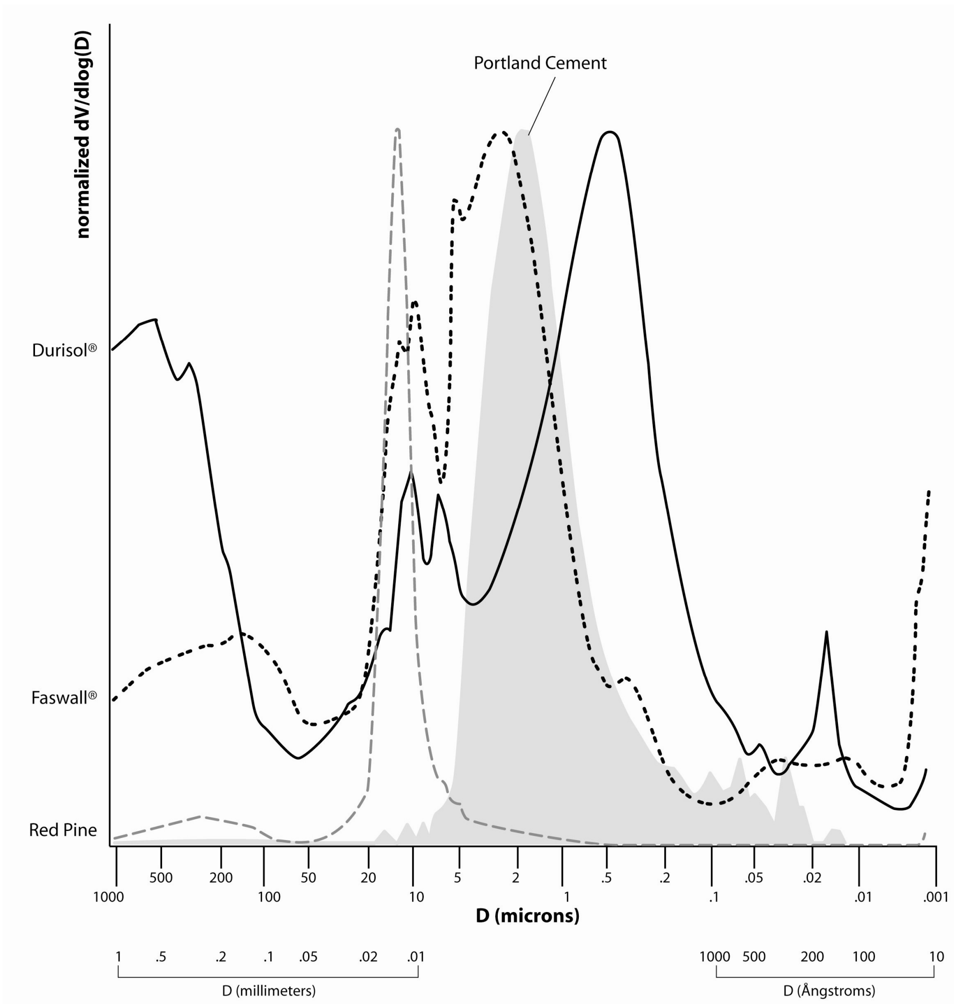

Figure 20. Pore size distribution, dV/log(D) versus D (where V=volume and D=-diameter), for Durisol® (solid black line), Faswall® (dashed black line), cured Portland cement without aggregate (grey shaded area), and a splinter of red pine (dashed grey line). Measurements were performed by the Quantachrome Corporation using a mercury porosimeter.

Moreover, from the large populations of macropores and "superpores" one can reasonably infer that the two materials have high water vapor permeability. The latter has been verified by direct measurements in the case of Durisol®. A one-inch thick slab of the material[165] was found to have a vapor permeance of 14 or 17 perms (dry cup and wet cup values, respectively, converted from the metric units reported by the company).[162] No perm data are available for Faswall®.

We would be remiss if we did not also point out the *differences* between the measured Durisol® and Faswall® pore size distributions. Both Faswall® and

[165] The thickness of the material for this measurement was not reported on the online document cited in footnote 162. We obtained it rather from a representative of Durisol Building Systems.

Portland cement have their largest peak centered near 2 microns, whereas the biggest Durisol® peak is centered just below 0.5 micron. Faswall® also has a peak just below 0.5 micron, but it is much smaller. Both low-density fiber-cement samples do show porosity around 10 microns, characteristic of the radial structure of wood as observed for the red pine sample. However below 0.05 microns (500 Ångstroms or 50 nanometers) the two materials look totally different. This is the size domain in which minerals, ultra-fine ceramic particles and colloidal gels exhibit their microstructure. Overall it appears that Durisol® has a sharper, more uniform microstructure, whereas the broader peaks observed for Faswall® suggest there may be a higher degree of variability throughout the microstructure.

When we showed a Durisol engineer these results he attributed this more uniform microstructure to the well controlled wood processing procedures that are followed at their facility. He said these procedures have been established as part of their ISO 9002 certification process, and help to create a well documented and repeatable procedure that has been developed by Durisol over the course of their 60-year history.

We also determined the *internal surface area* of each material from low-temperature nitrogen gas adsorption isotherms measured at Quantachrome. Results were as follows, in units of square meters per gram:[166] Durisol®, 47.2 m^2/g; Faswall®, 28.7 m^2/g; Portland cement, 11.2 m^2/g. Each of these values is relatively high and consistent with, but not necessarily indicative of, a tendency of the material to adsorb water vapor. That is, these results satisfy *one* of the three preconditions defined in section 6.4 for hygroscopic behavior. (The other two preconditions are the existence of a relatively high density of surface adsorption sites for water molecules and the presence of a permeable microstructure.) As it turns out, Durisol® and Faswall® satisfy *all* three preconditions. However, in the case of Portland cement, we believe the water adsorption sites in the mineral precursors are irreversibly destroyed by the extremely high temperatures used in the clinker manufacturing process.

Mechanical Strength. Despite having relatively low density and high porosity, both our breathable wall form materials have a high strength-to-weight ratio and are dimensionally stable. It is well known among material scientists that fiber-matrix composites like Durisol® and Faswall® are strengthened by the ability of fibers to stop crack propagation. Several different mechanical strength parameters, measured according to modified ASTM protocols, are given in Durisol's Material Properties document:[162]

Modulus of elasticity (compressive):	1500 MPa
Minimum modulus of rupture (7-day strength):	1.0 MPa
Minimum ultimate compressive strength:	2.0 MPa
Minimum shear strength:	0.2 MPa
Durisol-concrete bond strength:	0.6 MPa

To our knowledge there has been no laboratory mechanical testing of Faswall®, but ShelterWorks has plans to change this very soon.[160] It will be interesting to

[166] To help visualize these units, in section 17.4 we noted that a surface area of 50 m^2/g corresponds to the area of a football field for every pound of material.

see whether or not Faswall® is weakened at all by the usage of lower cement/wood ratios than those used to make Durisol®.

Durisol® and Faswall® wall forms are not load-bearing but become part of a load-bearing structure when filled with concrete and reinforcing steel or fiberglass rebar, as the concrete bonds with the form to make a monolithic structure. The latter does not occur with foam ICFs which have no porosity into which the concrete can penetrate. Because of the strong bonding between the wall form and concrete infill, Durisol® and Faswall® wall forms are successfully used in construction of buildings that are multiple stories high. Durisol® in particular has a long track record in high-rise commercial buildings and parking garages, where superior mechanical properties are needed compared to those required in residential construction.

Machinability. Durisol® and Faswall® wall forms can be easily cut with simple hand tools and have been installed in sub-freezing temperatures down to 22° F (although temperatures need to be above 32° F to fill the cores with concrete). Both materials take and hold nails and screws (number 8 or 10 deck screws should be used). See chapter 9 for a discussion of the use of Tapcon® screws (www.buildextapcon.com) or Simpson® NSP 2 Nail Stop anchor plates (www.strongtie.com) to support wall cladding by anchoring the screws to the wall form cores before they are filled with concrete. The Durisol and ShelterWorks builder's technical installation guides give extensive information on fastening cladding, wall board and masonry to their products.[156,167]

Fire Resistance. The wall forms from both manufacturers have a four-hour fire rating. Specifically, test results show zero flame spread, and, per the company website, "Unlike foam, Durisol® will not ignite, melt, sustain fire or release toxic smoke in the event of a fire."[168] For Durisol® they also report surface burning characteristics, as per ASTM E84, of 11 for the smoke developed index and 0 for the flame spread index.[162] Likewise the Faswall® block has no flame spread nor does it produce smoke, as per ASTM C-119-88, E-84-89a.

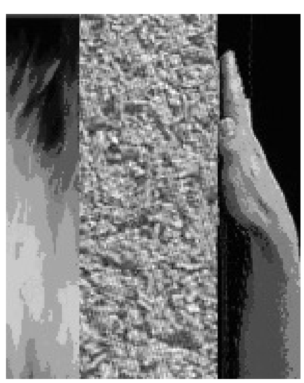

Figure 21. Fire resistance of Durisol® wall form. (Photo courtesy of Durisol Building Systems Inc.)

[167] Contact ShelterWorks Ltd. (541-929-8010; www.shelterworksonline.com) for the latest copy of their technical manual.
[168] See http://www.durisolbuild.com/Perf%20Overview.shtml.

Freeze-Thaw Resistance. Faswall® and Durisol® are both resistant to freeze and thaw cycles. Faswall® blocks passed the 300-cycle test according to ASTM C-666.[169]

Sound Absorption. Durisol® and Faswall® forms are sound-absorbing. Indeed Durisol® and others have made a good business of engineering and marketing low-density fiber-cement specifically for acoustic barriers around highways and railways. The company website states that

> Wall Sound Transmission Coefficient (STC) ratings can range between 54 and 72, while the Durisol® material itself provides Noise Reduction Coefficients (NRC) ratings as high as 0.95. This means that 95% of the sound that reaches the Durisol® material is absorbed and not reflected back into the airspace.[168]

Elsewhere the *minimum* noise absorption coefficient for a 50 cm (2 inch) thickness of Durisol® is listed as 0.75, as per ASTM C423.[162] Likewise, according to ASTM E 90-90, ShelterWorks reports an STC rating of 55.[169] Homeowners who live in dwellings made of these materials report that their homes are acoustically quiet, a feature well-appreciated by environmentally sensitive individuals living in noisy urban environments.

Electrical Conductivity. For the *electrical* conductivity of low-density fiber-cement we have no hard data, but like the *thermal* conductivity it should be greatly reduced (see Thermal Properties below) compared to that of concrete made from Portland cement, owing to the minimal amount of trapped liquid moisture as well as the introduction of wood fibers that interrupt conductive pathways within the composite material. The significant result is that wood-concrete composite building envelopes cause none of the health problems mentioned in the last section that have been attributed to Portland cement. In fact, employers in Germany have reportedly cut out portions of the concrete floor beneath factory assembly lines and replaced the concrete with electrically insulating, cork-covered cement-bonded wood fiber board over direct earth for workers to stand on. By doing so the workers have been shown to increase their productivity and decrease their absenteeism and medical expenditures. (Inspired by this report, George has developed an alternative slab and foundation protocol for use in homes, described in chapter 11. That involves laying crushed pieces of low-density fiber-cement block over a gravel bed, upon which you then pour a Portland cement slab. You then either coat the slab with a nonconductive layer of magnesium phosphate cement or, more conveniently, lay sheets of magnesium oxychloride cement composite board. George acts on the theory that by providing an abundant supply of readily available electrons above and below a poured slab made with Portland cement, the slab will not pull electrons from the bodies of occupants standing, sitting or sleeping above the slab, thereby preventing what some term, "concrete sickness.")

Electrostatic Characteristics. There has been no actual testing to our knowledge of either material, even though ShelterWorks says on its website that

[169] See www.shelterworksonline.com.

"For those interested in Bau Biologie, Faswall™ has [*sic*, produces] an [air] ion ratio of 60% negative : 40% positive–approximates the outdoors."[170] This statement reflects our *expectation* for both Faswall® and Durisol®.

RF Attenuation. It has been found that buildings with cement-bonded wood fiber wall forms have the capacity to block incoming radio frequencies (RF) much more effectively than conventional wood-frame, batt-insulated construction.[171] This property is attributable to the Portland cement that's a component of the fiber-cement composite material as well as the filled core of the wall forms, for cement is known to absorb radio frequencies. This feature is important to electromagnetically sensitive individuals, and, we believe, to the public at large as well. For a discussion of this characteristic, see chapter 6.

We will now consider, in separate subsections, the outstanding breathability and thermal performance of low-density fiber-cement.

Breathability

Let us now examine the trio of properties that pertain to the degree of breathability of a material, as defined in chapter 6: vapor permeability (section 6.3), hygroscopicity (section 6.4), and capillarity (section 6.5). As it happens, in each of those sections we have used some of the reported research findings on Durisol® cement-bonded wood fiber wall forms as examples and performed tabular comparisons of this low-density fiber-cement to other building materials. So we encourage you to revisit those sections.

Walls made with cement-bonded wood fiber wall forms adsorb excess water vapor from indoor air and release that moisture when interior relative humidity declines. This has been proven in the case of Durisol®, as described in section 6.4, and a quick experiment we conducted on a sample of Faswall® demonstrates that Faswall® also has the potential to buffer humidity. Specifically, we observed an 8.3% weight loss for an old sample of this material[172] upon decreasing from 50% to 0% relative humidity. *[For the published edition we will revisit our weight loss experiment using a larger sample provided by ShelterWorks Ltd. –Ed.]* Reading the adsorption isotherm for Durisol® measured by Straube and Achyra that is reproduced in section 6.4, Figure 7, page 30, we see that the equilibrium moisture content for that material at 50% RH is also about eight percent. Provided that the exterior is not sealed with a vapor-impermeable retarder, a practice we discourage, any moisture that enters the wall can also easily escape to the outside due to the low-density fiber-cement's high vapor permeability and its free-draining behavior resulting from extremely large pores that break all capillary action.

[170] See http://www.shelterworksonline.com/product.html.

[171] Robert Stellar, lecture presented at International Institute for Bau-biology® and Ecology Alumni conference, November 2006, Santa Fe, New Mexico.

[172] This sample was provided by Leni Walter of K-X Faswall International Corp. in April 2006 and is the same material used for the surface area and pore size distribution analyses.

Cement-bonded wood fiber wall forms (at least Durisol®, which has been demonstrated to behave this way; our own porosity studies reported in the previous subsection strongly suggest that Faswall® behaves in similar fashion) also allow minor amounts of air to *slowly* pass through the wall structure, which provides a small degree of indoor air purification without loss of thermal performance. The *Bioenergy Update* newsletter states (based on Faswall's marketing literature that is apparently based largely on studies conducted by Durisol):

In contrast to tightly sealed wall systems, the wood-concrete shell and webs in a FASWALL® structure create a very slow air exchange, which keeps the wall dry. Condensation is prevented, thereby eliminating the conditions for mold growth and "sick-building syndrome." This breathing ability also allows the concrete fill to cure faster and more completely as the hydration moisture can evaporate through the whole wall system and not just thru the top as in the foam systems.[173]

The immensely hygroscopic nature of Durisol® cement-bonded wood fiber wall forms was documented in an excellent study conducted by John Straube, Assistant Professor and Research Engineer, Civil Engineering Department and School of Architecture at the University of Waterloo, Waterloo, Ontario, Canada. Straube authored a paper with Vipul Acharya, Vice President of Durisol Building Systems Inc., Hamilton, Ontario.[174] Key findings of this paper are presented in some detail in chapter 6, but an appreciation of these characteristics in a breathable wall material such as low-density fiber-cement is so important that we mention them again in the next three paragraphs.

In the study Straube and Acharya prove that Durisol® cement-bonded wood fiber wall forms finished on the inside with lime plaster provide significantly improved indoor air quality compared to conventional wood frame walls. They surmise this is due to their high vapor permeability and strongly hygroscopic nature, which reduce fungal growth. The material has the unique ability to allow slow diffusion of moisture vapor while also being able to store excess moisture in the adsorbed state.

According to the study, "When compared to other common building materials the vapour permeability (i.e., the permeance per unit thickness of material) [of Durisol®] is clearly much higher." It goes on to say, "As the humidity climbs from 30% (relatively dry air) to over 70% (a humid environment), Durisol adsorbs more than 7% of its dry mass in water vapour."

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[173] See *Bioenergy Update*, June 2002, Vol. 4 No. 6, "FASWALL® 'Wood Concrete'", available at http://www.bioenergyupdate.com/magazine/security/Bioenergy%20Update%2006-02/bioenergy_update_June_2002.htm.

[174] V. Acharya and J. F. Straube., "Indoor air quality, healthy buildings and breathing walls," in the *Proceedings of 1998 Excellence in Building Conference*, Washington D.C. The manuscript was posted at http://oikos.com/library/breathingwalls. A slightly enhanced version by J. F. Straube and J.P. deGraauw was published under the title "Indoor Air Quality and Hygroscopically Active Materials" in the *ASHRAE Transactions, volume 107, part 1* (2001).

Studies conducted by Straube further showed that short-term rises in indoor air relative humidity (RH) can result in fungal growth, even if the overall RH is well below levels that usually support the growth of mold. Straube writes:

> Hygroscopic, "breathable" walls operate automatically, require no energy and cannot break down (that is, mechanically fail as ventilation equipment does). Such walls can also react much more quickly than ventilation. Ventilation and breathing walls are likely best used as complementary techniques for ensuring IAQ.

Even when these wall systems do become wet, as in a heavy rainstorm or a water pipe leak, they do not promote mold growth. One example among many was presented in the previous subsection in which a Louisiana resident reported the ability of his Faswall® home to resist the high levels of humidity so common in the deep South. His home also sustained no mold growth after Hurricane Katrina when many rain-soaked wood frame structures around him became filled with mold.

As a further example, see the following quote from the Durisol Building Systems website stating that in tests performed by the University of Waterloo and other institutions, a relative humidity level high enough within the walls to promote mold growth could not be artificially induced:

> …the Durisol material … acts as a vapour regulator. The material acts as a buffer for vapour diffusion and moderates the RH (relative humidity) levels within the interior. We have conducted full scale wall tests and found that not only did the walls not create any condensation problems without a vapour barrier, but RH levels above 65-70% were not possible. This means that we could not even get to the level required where mold can start to grow. This combined with the high pH (alkaline) environment, means that the wall system actually helps to inhibit mold growth. Something that doesn't happen with the other systems.[175]

ShelterWorks explains on their website how their Faswall® wall form deals with the issue of water intrusion:

> Do the wood chips get wet and rot inside the wall? No, the internal wooden structure is not compromised by moisture. The mineralization process neutralizes the naturally occurring sugars found in cellulose fiber which is normally the "food" source for fungus to breakdown the fiber. The cement coating provides further protection of the wood fiber and finally, the wood cement composite has thousands of capillaries through which water vapor can travel and not remain in the wall.

The website continues by saying, "How do your wall forms stand up against mold … ? The high alkalinity of the composite material along with its inability to build humidity eliminates any mold threat."[169]

Remember, builders must change their thinking from asking the question, "How tight can I make this wall?" and begin asking, "How will this wall handle the

[175] See http://www.durisolbuild.com/faq.shtml.

moisture that will inevitably enter at some point in its life?" Our goal is to help you build an envelope with as much capacity for drying as possible while maintaining good thermal performance.

Thermal Performance

Cement-bonded wood fiber wall forms are designed to thermally insulate because air between the wood chips contained in the jacket provides a matrix that creates a high insulating value. For those familiar with thermal conductivity values, Durisol reports 0.083 W/(m·K) for their typical, 500-600 kg/m^3 wall form material. They add that values of only 0.072 to 0.077 W/(m·K) have been measured for even lower density materials (400-430 kg/m^3).[162] This translates to an R-value of 1.75 per inch.[176]

Unfortunately Faswall and ShelterWorks have not actually measured the thermal conductivity of their Faswall® material. ShelterWorks calculates their stated R-values[158] assuming that the value of R 1.75 per inch for the wall form jacket material, which they have been told was used for Faswall® for many years, is correct.[177] Interestingly, this is precisely the same value that Durisol Building Systems has determined for Durisol® on the basis of the above thermal conductivity measurements. Given that the two low-density fiber-cement materials apparently have similar density values, the assumption made by ShelterWorks is plausible, though not necessarily correct, as we have shown that the microstructure can differ significantly. The good news is that ShelterWorks' Thomas Van Denend acknowledges this testing deficiency and is making arrangements to sponsor university studies of their Faswall® material's thermal performance in 2008. Mineral wool (also known as rockwool)[178] inserts are added by both manufacturers for extra insulating capacity (which we call "out"sulation, as explained in section 6.6) in blocks used for exterior walls and foundations. As a result, Durisol® and presumably also Faswall® wall forms meet or exceed building and energy code requirements in all states.

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[176] See http://durisolbuild.com/F%20R%20Value.shtml.

[177] Tom Van Denend, personal communication with Wayne Federer, November 26, 2007.

[178] Although there are still differing viewpoints among specialists regarding its safety, rockwool has been embraced by the Scandinavian green building industry and associated government agencies regulating their "passive house" market. Indeed the rockwool industry has in the last ten years made the fibers more soluble, shortening lifetimes for ingested fibers in the lung from a typical half-life of 300 days down to 20 to 60 days. Animal studies have allegedly indicated most of these newer materials to be non-carcinogenic under all but very restricted conditions of exposure. Nevertheless the Institut fur Baubiologie und Oekologie in Neubeuern, Germany (IBN) has maintained (in a September 2002 update of their correspondence course) that we cannot know at what moment the ingested fibers become carcinogenic. IBN states that the increased bio-solubility of these fibers is a step in the right direction but that the situation does not merit a blanket all-clear signal. We join IBN in urging precaution and recommend against the adoption of rockwool except in situations where it is more-or-less hermetically sealed within building materials as, for example, it is after it has been placed inside a low-density fiber-cement wall form. We therefore urge care in handling individual wall forms before a wall has been assembled. We also present (see section 9.3) the option of using cellulose, cotton or straw insulation in lieu of rockwool as the insulation placed within the core.

Thus the cement-bonded wood fiber jacket of these wall forms provides insulation that standard concrete masonry unit walls and foundations cannot. The mineral wool inserts add increased insulation. No additional insulating material is needed above or below grade. This ensures the same thermal performance as a standard ICF foundation or above-grade wall without the use of foam board. According to the Durisol Building Systems website, "The basic Thermal performance of a standard Durisol Wall Form is R-8 (true steady-state 2 dimensional value). The performance of this wall assembly is equivalent to 1.5" continuous Styrofoam on a CMU or concrete Wall".[179] This value increases to a steady state two-dimensional R-value of up to R-28 for the thickest Durisol® block with a mineral wool insert, effectively twice as much as a wood-frame wall with spun glass insulation[180].

Cement-bonded wall forms cost more than conventional wood frame batt-insulated walls, but as explained in section 6.6, because they are a thermally massive wall material they pay for themselves in energy savings. For example, the owners of a commercial building made with Faswall® wall forms in Iowa City, Iowa reported in 1999 that they pay approximately $300 per month for heating costs in winter for their 21,000 square foot building. At the time this was comparable to what a family would normally pay to heat a standard wood-frame home that was a fraction the size of the Faswall-built commercial building [147,169]

Depending upon the degree of insulation needed and the intended use of cement-bonded wood fiber blocks, one can choose from among various available thicknesses, ranging from six to fourteen inches for the Durisol® wall form. Durisol makes six- and eight-inch wall forms for non-load-bearing inner partition walls, while ten-, twelve- and fourteen-inch wall forms are used for exterior walls both below and above grade. ShelterWorks' Faswall® forms are all twelve inches thick at this time.

Inserts of mineral wool are installed at the Durisol Building Systems factory into the core of their ten-, twelve- and fourteen-inch forms to provide additional insulation when they are to be used as exterior walls above grade. ShelterWorks also inserts insulating pads into its twelve-inch Faswall® form. For below-grade application, Durisol Building Systems typically does not recommend rockwool inserts (although some customers do order Durisol® foundation forms with inserts for maximum insulation), whereas ShelterWorks does recommend inserts when its forms are used as a foundation. The inserts for both companies are fire- and moisture-resistant and made from recycled rockwool material.

As we explained in section 6.6, the combination of positioning the rockwool toward the outside of the core along with having a cement-bonded wood fiber jacket that is itself insulating places the bulk of the wall's total insulating capacity to the outside of the concrete core. This effectively isolates the thermal mass of the block to the inside of the wall, having the effect of smoothing out temperature swings within the indoor living space. On the other hand, a polystyrene-containing ICF wall *isolates* the thermal mass of the wall's cement inner core from the living space indoors by placing half of the wall's insulation between the cement core and the indoor air. This disallows the homeowner from

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[179] See http://www.durisolbuild.com/products_standard.shtml.
[180] See www.ecobuildingconcepts.com.

taking full advantage of the thermal mass that ICFs would otherwise provide from their concrete core. The core's thermal mass is readily available for holding and releasing valuable heat to the homeowner who uses cement-bonded wood fiber wall forms.

Recall from chapter 6 that when the term "thermal mass" is applied to the envelope of a house it simply means that walls will absorb heat when the indoor air temperature is warmer than the wall itself, and they slowly release heat over a prolonged time interval when the indoor air temperature is cooler than the wall. We use this principle when we realize that modern buildings generally absorb more heat than they lose when sunlight enters south-facing double glazed windows. When high-efficiency, low-E, triple-pane windows are installed, even more heat is gained. None of this heat from the winter sun can be stored in the building structure to any significant degree, however, when walls and floors have no appreciable thermal mass, and most wood-frame homes do not. This free heat from the sun is unfortunately wasted in most homes built in North America. A design incorporating thick walls on all sides of a building and solid-surface (colored concrete, stone or ceramic tile) flooring under south-facing windows, on the other hand, enables storage of the sun's heat for use at night and on the next cloudy morning. Even more heat is stored if thick materials are also used for interior partition walls.

When measured in the steady, two-dimensional state, Durisol® wall forms possess an R-value of approximately 1.75 per inch, creating a range from R-8 to R-28for their blocks depending upon thickness and whether inserts are present.[176]

As indicated previously, ShelterWorks *assumes* an R-value of 1.75 per inch and calculates that their Faswall® twelve-inch form has R-values of R-12 with no inserts and R-21 with 3-inch mineral wool inserts. Faswall® blocks reportedly have, "Performance R values [that are] significantly higher depending on glazing quality, southern exposure and climate."[169] We look forward to the publication of more meaningful, experimentally-based thermal data by ShelterWorks in the next year.

Recall from chapter 6 that Oak Ridge National Laboratory came to the conclusion that when you base thermal performance for a wood frame house upon R-value alone, it is generally overstated. Durisol Building Systems' website states that "They [Oak Ridge Lab] found that a wall system with 2x6 studs at 24" on center and R-19 batts had a true 'whole wall' R-value of 13.7."[181] This is due to thermal bridging of heat and cold right through the wood framing members from inside to outside.

When tested in steady-state indoor conditions in a laboratory, fiberglass batts outperform either the Durisol® or Faswall® wall form as an insulating material. However, as Oak Ridge National Laboratory points out, this is not a valid comparison because many factors come into play when houses are analyzed in the field. [181,182] These include the composition of the wall itself, the framing

181 See http://www.durisolbuild.com/Webdocs/Durisolthermalperformance.pdf.
182 Jeffrey E. Christian and Jan Kosny, "Wall R-Values that Tell It Like It Is," *Home Energy*, March/April 1997, available at http://homeenergy.org/archive/hem.dis.anl.gov /eehem/97/970308.html.

around windows, doors and corners, and diurnal (daily) and seasonal climatic changes. Wood frame walls allow thermal bridging, meaning that heat can transmit to the outside right through wood studs by as much as 2.5 °F., especially at corners, windows, wall partitions and floor joists. Likewise cold outside air can infiltrate between two adjacent wood studs.

Walls built with Durisol®, on the other hand, avoid thermal bridging, ensuring that the cement core remains virtually as warm as the web of the wall throughout the winter, varying by no more than 0.2 ° F in computerized wall simulations of the Durisol® wall form.[181]

Another advantage of Durisol® and Faswall® over wood-frame walls is the thermal mass contained within the cement core, which absorbs and holds radiant heat from the sun for many hours. To quote Durisol Building Systems from their thermal performance document:

> A thermally massive wall with a much lower steady-state R-value (the value normally quoted) is considered the equivalent of a lightweight framed wall by ASHRAE. Conversely, using a Durisol Wall Form with the same or slightly less than the R-value typically quoted for a framed wall will result in significant space heating energy savings and improved comfort.[181]

In summary, the use of R-value as a means of measuring thermal performance is valid only when comparing similar construction methods. In modern construction, R-value is used to compare lightweight wood frame structures with each other because their composition is generally the same. When comparing the R-value of lightweight wood frame buildings to those built with Durisol®, Faswall®, or any of the other thick wall materials mentioned in this manual, however, a simple comparison of numbers is not valid. The whole-wall R-value and the thermal mass, or lack of it, contained in both buildings must be taken into account, not just the nominal R-value, because the building methods are so different.

Durability

Cement-bonded wood fiber blocks are durable enough to last for hundreds of years. Switzerland reportedly certifies homes to be durable enough to stand at least four hundred years, a far-sighted goal that that country has set for ideal housing construction, and, according to George, has bestowed that distinction on the Durisol building material.

For sixty years in Russia and throughout the entire territory of the former Soviet Union, builders have been using the Arbolit brand of cement-bonded wood fiber wall forms. The company website noted that Arbolit structures built in the 1960s in locations characterized by severe temperatures and frost, such as Kazakhstan and Antarctica, have fared much better than those constructed of reinforced concrete or brick.[183]

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183 We learned this in an article on Arbolit translated from Russian, entitled "Biotechnological Properties and Designs Based on It," appearing at http://www.arbolit.com/articles2.htm, last accessed in October 2007 but apparently no longer online.

In addition the Durisol® Technical and Installation Guide states that in six years of testing by the US Forest Service at termite facilities in Mississippi and Arizona, Durisol® placed both below and above grade showed either no feeding or surface investigation by termites, or surface investigation only with no penetration into or damage to the material.[184] Likewise, ShelterWorks website also states that The University of Georgia has conducted tests proving that Faswall® wall forms resist termite damage.[169]

Cement-bonded wood fiber wall forms also have a particular advantage that is increasingly important in this age of global climate change. Walls made of these materials have the capacity to withstand high winds and seismic events. The mass and design of the Durisol® and Faswall® wall systems enable a building to sustain hurricane-force winds and earth tremors.

For instance, Faswall® is advertised as "suitable for all seismic zones"[185] and was shown to sustain 130 mile an hour winds during Hurricane Katrina, according to a Louisiana homeowner, Jonathan Reily, whose Faswall® house had no damage.[186] In fact, it remained quite stable despite the force of hurricane winds outside, and the homeowner and friends (who had to leave their own homes due to flooding) all said they did not realize the degree of destruction until the hurricane passed because "the house was so quiet" during the storm.

In addition to the absence of wind damage, Reily also noted the dry indoor living conditions without mold during the extreme humidity of a typical Louisiana summer and his home's ability to retain heat during their admittedly mild winters.

Sustainability

Compared to conventional building materials, cement-bonded wood fiber wall forms have features that are more sustainable and healthy for the environment, helping to satisfy several important criteria for certification by the U.S. Green Building Council's LEED (Leadership in Energy and Environmental Design) program and other green building guidelines. The use of wood, a renewable resource, offsets to some degree the embodied energy contained in the concrete used for binding the chips and filling the cores. Furthermore, the wood used in both Durisol® and Faswall® wall forms comes from sources that would otherwise go into the waste stream.

More importantly, the amount of cement used in the core of both products is approximately one half that used in conventional polystyrene-containing ICFs. Furthermore, no chlorofluorinated hydrocarbons (CFCs) or HCFCs are released into the atmosphere during the manufacture of cement-bonded wood fiber wall forms[187]

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[184] Reference 156, p. 11.
[185] See http://www.shelterworksonline.com/product.html.
[186] A testimonial letter from the homeowner is posted at http://www.shelterworksonline.com/news.html.
[187] See http://www.durisolbuild.com/F%20Compare.shtml.

In addition, because cement-bonded wood fiber wall forms contain no toxic chemicals or polystyrene, they are fully recyclable. The Durisol Building Systems uses recycled blocks of its own material when they manufacture new wall forms. Ken Roseboro's article on Faswall® in *Concrete Products* magazine quotes Hans Walter as stating that up to half of the estimated 9.6 million tons of waste wood created each year in the US is "burned, dumped or buried in landfills" (Faswall uses waste wood in the manufacture of its wall forms). Ken goes on to say, "According to Walter, 1.6 million tons of waste wood could produce enough Faswall® block to build nearly 300,000 1,800-sq.-ft. homes."[147]

Finally, cement-bonded wall forms can be made with up to 3% fly ash,[173] also considered a sustainable practice. Blocks can be ordered without fly ash for those homeowners who want to avoid the use of this material, considered toxic by our profession because it comes from the lining of smoke stacks and other industrial processes and can contain heavy metals.

Cost

Builders to whom we talked (see section 9.4) reported the installed cost of a building envelope using cement-bonded wood fiber wall forms to generally be 5 to 15% more than that for a conventional wood-frame, batt-insulated wall. That represents a 1-3% increase in the overall cost of the house. Costs vary somewhat due to shipping, depending upon your location relative to the two manufacturers. Durisol® is located in Hamilton, Ontario and ShelterWorks is in Corvallis, Oregon.

The cost of building a home with cement-bonded wood fiber wall forms is comparable to the cost of building a home with ICF and SIPS materials. As with modern ICF homes, using cement-bonded wall forms pays for itself in energy savings, lower maintenance costs and durability compared to conventional wood-frame construction, providing a pay back within a few short years. This also allows the home to retain a higher resale value.

According to a Durisol representative, their wall form is cost-competitive as a foundation with poured concrete which is $4/square foot unfinished. 10-inch Durisol® blocks are $6-7/sq. ft.

One important advantage with both products is the ease of construction. Savings come from reduced labor time and materials. You avoid the need for framing, extensive carpentry, and insulation. The following quotations illustrate these savings, applicable to both wall form manufacturers:

> [K-X Faswall] Company officials say no additional insulation, exterior sheathing, bracing, or "wrap" is needed. Thus building costs are reduced by reducing material and labor costs for construction.[173]
>
> Strong and energy-efficient: The Faswall® system offers many advantages, according to developer Walter. It can reduce construction time by 20 percent and cost by 5 percent, he notes. A building can be

constructed faster than with conventional block because the forms weigh less and require no mortar.[147]

Using these wall form materials makes good economic sense and moves homeowners away from the concept of building a home as an investment, to be "flipped" when the market makes selling advantageous. These homes are meant to be lived in for decades and provide a sound return on investment, not to mention increased comfort, health and quality of life for you and your family. Lower heating, cooling and maintenance costs reduce your "life-cycle" costs, and when you add in less trips to the doctor, now you also have lower "total cost of ownership."

Final Remarks

The Durisol®, Faswall® and ShelterWorks websites contain a wealth of technical information for the designer, architect and builder on the use of their wall forms, including downloadable technical guides or manuals. See chapter 9 for a detailed discussion of how low-density fiber-cement wall forms are used on site, including installation techniques and the use of magnesia-based stuccos and mineral paints, as well as below-grade waterproofing protocols.

Lastly, near the end of the present chapter, following a lengthy introduction to healthy alternative cements, we will discuss newly developing options in low-density fiber-cement made without Portland cement.

8.9 Healthy Alternative Cements

In the last section we introduced you to concrete made from Portland cement and pointed out some of the major pitfalls of the conventional cement of the nineteenth and twentieth centuries. "Alternative cement" encompasses everything else, including thousand-year-old traditional recipes as well as those newly conceived in the world of chemical ceramics. As long as one avoids using products with toxic polymeric additives, most alternative cements are far more breathable and less electrically conductive than Portland cement. Fortunately outstanding performance can be achieved using a range of alternative formulations that are not "contaminated" with "suffocating" synthetic organic chemicals. Therefore this section will be limited to biologically and environmentally compatible technologies, with an emphasis on current or potential building envelope applications.

History, Properties and Benefits

Before the widespread 20th century use of Portland cement, cements based on magnesium oxide, magnesium chloride and phosphate minerals were popular worldwide. Once the introduction of Portland cement essentially cornered the market in the latter part of the 19th century, serious public health issues began to be quietly recognized, documented, and scientifically verified as being directly linked to the use of limestone/gypsum based cement and concrete products. (See section 8.6.) In contrast to this sobering reality, cements based on magnesium compounds have consistently proven to be superior in strength, versatility, and environmental integrity.

So why were these magnesia-based cements virtually abandoned over the past 175 years? First of all, the story of cement and concrete does not have any bad guys, only good guys. Whether we are discussing Portland cement or any other cement, no one ever purposely set out to make a problematic cement; in fact, quite the opposite. When Joseph Aspdin invented his water-activated Portland cement in his Leeds, England kitchen in 1824, it obviously seemed to be a viable and exciting advance in addressing the accelerated pace of the industrial revolution. And in many respects, notably its convenience and availability, it was!

It was only as this nineteenth century cement/concrete innovation spread around the world that its previously unrecognized, negative side effects would slowly but surely begin to surface and become scientifically scrutinized. It is also important to note that Portland cement manufacturers continuously allocate enormous amounts of R&D funding in a valiant effort to overcome these inherent deficiencies. Literally billions of dollars are spent in an effort to do what magnesium oxide, oxychloride and phosphate-bonded cements are able to do "naturally."

To understand this dilemma a discussion of the history of magnesium compound-based cements is included in this chapter, which will explain why these ancient building materials are of such great historic importance. More importantly we'll see why the same low-temperature ceramic bonding techniques used over the centuries in the making of magnesium-based cements now hold the key to the future of worldwide, sustainable building practices. This currently available cement alternative (often referred to as "chemical ceramic cement" or simply "ceramic cement") provides unique, short- and long-term solutions to the adverse health and environmental effects of Portland cement while at the same time offering improved performance. Furthermore, the introduction of magnesium oxide-based structural sheets, discussed separately in a later section (8.11), is about to turn the North American construction industry on its ear because they offer a waterproof, mold-free alternative to wood-based sheeting and decking.

Magnesium deposits, in the form of the mineral magnesite (magnesium carbonate) or seawater brines containing magnesium hydroxide (the active ingredient in milk of magnesia) and magnesium chloride, exist in abundance in every corner of the earth and cover roughly 8% of the world's surface. Depending upon where the raw materials are mined, cement products derived from magnesium oxide (MgO, also called "magnesia" by chemists and ceramists) and magnesium chloride require only twenty to forty percent of the energy required to produce Portland cement. Phosphates are available from many sources ranging from phosphoric rock to animal wastes and fermented plants, which historically were used to "react" with various oxides to produce these environmentally friendly, nontoxic cements.

Blends of magnesia with phosphate minerals or magnesium chloride were used in ancient times in Germany, France, Mexico and throughout Latin America, Switzerland, India, China and New Zealand, among other countries. The Great Wall of China and many of the Stupas in India, still standing today, were all made with magnesia-based cements. Ancient European artisan builders used timber frame construction with magnesia-based cement infill. No gaps are visible in these 800-year-old walls that remain in use today.

Germany had craftsmen who blended magnesia as a building material for centuries, and right up to World War II this practice had been a labor-intensive family tradition. That tradition was abandoned after the war, except for the "magnesite-bonded wood wool" technology described below in Commercial Products: Magnesium Oxysulfate. Durisol and other low-density fiber-cement companies sprang up to fill the gap and facilitate the quick rebuilding of all of Europe.

Until the early 1930's almost all "terrazzo" floors were made with magnesia or magnesium oxychloride. Many exteriors in San Francisco are covered with magnesia-based stucco that has not cracked in one hundred years with all the tremors and earthquakes that that city has endured. Magnesia-based cements were used extensively throughout the United States until Portland cement offered what appeared at the time to be a less-costly, user-friendly alternative. The successful manufacture, marketing, and proliferation of Portland cement occurred at a time when energy was cheap and the harmful health and environmental effects of the cement were not known.

Magnesia-based cements have exceptional health-promoting properties for occupants of homes in which they are used as a building material. For example, research at Argonne National Laboratories has documented that occupants of homes made with traditional cow dung and magnesia located right next to the Chernobyl nuclear power plant had less radiation sickness from the nuclear accident than any other group, while a higher number of occupants of more modern wood frame and concrete homes located several miles away succumbed to radiation sickness.[188]

The ability of at least some magnesia-based cements to shield ionizing radiation does not predict similar efficacy for radiofrequency radiation and no formal studies have been conducted of the latter, however Texas consultant Jim Beal, an engineer and expert in the field of bioelectromagnetics, has done some measurements suggesting that there is indeed some beneficial absorption of radiofrequencies and/or microwaves.[189,190]

These cements bind naturally and exceptionally well to all things containing cellulose (i.e. plant fibers, wood chip, wood framing, etc.) and are often referred to as "living cements." This is in sharp contrast to Portland cement, which under normal conditions repels cellulose and often requires plastic binders to assist in its "artificial" adhesion to wood, polystyrene or stone. These petroleum-based binders seriously restrict the capacity of Portland cement to "breathe," or naturally convey water vapor, thereby trapping moisture within it and increasing

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188 Arun Wagh, personal communication with George Swanson.
189 Jim Beal, personal communication with George Swanson.
190 At http://www.emfinterface.com/bldginspad.htm (last accessed in November 2007 but no longer posted), Jim Beal writes in a paragraph about microwave shielding that "Use of magnesium oxide (MgO) in stucco or plaster, replacing cement, can provide … [s]ome shielding."

the likelihood of mold damage. When the newly available, "water-activated" magnesium oxide-based cement formulas were introduced, however, as a "cap coat" over damp Portland cement floors, the moisture in the slab could then breathe, meaning it could dry out through the magnesium oxide coating, which remains intact rather than delaminating like epoxy/cement composites often do.

Magnesia-based cements commonly achieve compressive strengths of 9,000 to 45,000 psi (pounds per square inch) and tension strengths in excess of 800 psi, many times stronger than conventional concrete. Magnesium oxide and magnesium phosphate combined with clay and cellulose forms a cement that breathes water vapor, a significant plus. The clay adsorbs excess moisture without getting wet, and the ability of magnesia-based materials to dry enhances the movement of moisture. Therefore materials made with these mineral mixtures never rot.

Magnesia-based cements are also highly non-conductive of electricity, heat and cold, and they have been used for flooring in radar stations and hospital operating rooms throughout the twentieth century. Another example from history is that, unlike Portland cement, magnesia-containing cements having as little as 20% magnesium oxide content would not drain the charge out of a rubber-encased car battery left overnight on a cement floor.[191]

Here we begin to address another reason why magnesium oxychloride and phosphate-bonded cements eventually were forced to take a back seat in building the foundations of our modern world. In a nutshell it comes down to the relative cost of the necessary raw materials. The superiority of ceramic cement is indisputable, even amongst a growing number of cement/concrete experts throughout the world, but the cost per pound compared to conventional Portland cement has relegated the use of magnesium mineral-based cements to value-added products. Yet Portland cements cannot begin to compete with the quality and strength of these magnesium-containing cements, so the cost premium is often warranted for a natural, nontoxic, breathable, sustainable product. New manufacturers in the market are beginning to produce magnesia-based products at more affordable prices.

CONCRETE RAINFOREST?
By Tony Smith
[Reprinted by permission]

There is a way to make our city streets as green as the Amazon rainforest. Almost every aspect of the built environment, from bridges to factories to tower blocks, and from roads to sea walls, could be turned into structures that soak up carbon dioxide, the main greenhouse gas behind global warming. All we need to do is change the way we make cement. John Harrison, a technologist from Hobart, Tasmania, reckons his alternative cement based on magnesium carbonate rather than calcium carbonate, could reduce

[191] Unlike older, rubber-encased car batteries, today's car batteries have molded polypropylene cases that do not leak electrolyte. The latter created the electrical circuit that drained older batteries placed onto a grounded conductive surface such as a Portland cement slab. (Newer batteries also have paper separators between the anode and cathode, whereas older batteries had glass separators that sometime broke when the battery was dropped onto a concrete surface. This was another occasional cause of battery discharge.)

climate change without sacrificing modern living. It's a big claim, and Harrison has set about trying to convince the building industry to adopt his ideas.

"The Kyoto Protocol was a good effort," says Harrison "but it got things wrong when it assumed that trees were the only things that could absorb carbon from the air." Instead, he wants to replace the ubiquitous Portland cement with a substance that he calls 'eco-cement'. "This magnesium based material," he says, could be cheaper to manufacture than Portland cement, more durable and soaks up CO_2 as well," and, claims Harrison, "if the building industry listens, cities and their suburbs could turn into sinks for CO_2, as effective as, for example, the natural grass and woodland they replaced." Our modern world is largely built of Portland cement, invented almost 180 years ago by a Yorkshire stonemason named Joseph Aspdin. In 1824, he obtained a patent for "an improvement in the modes of producing artificial stone" that involved roasting chalk and clay in a kiln, grinding the resulting 'clinker' into a fine powder containing mainly calcium silicates and mixing it with water. This starts a complex chemical reaction that forms crystals of calcium silicate hydrate, for example, which hardens the mix.

The 19th century was a time when the great cities of Britain were under construction, and many other inventors were working on artificial stone. But Aspdin cracked the problem by subjecting the ingredients to the ultra-high temperatures of a glassmaker's kiln in his home town of Hunslet. He called the product Portland cement because of its resemblance to the most popular natural stone of the day, from the Isle of Portland in Dorset. Portland cement proved cheap to make and immensely versatile, and soon became the basic ingredient of both cement and mortar, the building blocks of every city on the planet. Every year, some 1.7 billion tonnes of Portland cement are now produced worldwide, a staggering quarter of a tonne for every 6 person on Earth. But there's a problem. The manufacture of Portland cement produces massive amounts of CO_2. This is partly because of the huge amounts of energy required to raise temperatures inside cement kilns to the 1450 ˚C needed to roast the calcium carbonate (from chalk or limestone. And it's also because the process of conversion itself creates CO_2.

For every tonne of Portland cement emerging from the kilns, roughly a tonne of CO_2 gas escapes into the atmosphere. Cement manufacture is responsible for around 7 percent of total man-made CO_2 emissions worldwide, a figure that rises above 10 percent in fast-developing countries such as China, which currently manufactures one in every three tonnes of cement made around the world. If we mean to control global warming this situation can't go on. And, says Harrison, it need not. His solution, being brought onto the market by his small company 'TecEco' is to replace the calcium carbonate in the kilns with magnesium carbonate – a rock that occurs widely on its own, as the mineral magnesite, or in mixtures with calcium carbonate, such as dolomite. Magnesium based cements aren't new. They were first developed in 1867, by French man Stanislas Sorel, who made cement from a combination of magnesium oxide and magnesium chloride. However, his mixtures couldn't stand long exposure to water without losing their strength. Put a tower block of the cement in a Manchester or Seattle drizzle and it would eventually crumble away. Harrison's magnesium carbonate based 'eco-cements', on the other hand, are chemically quite similar to calcium carbonate based Portland cement, are far more robust than Sorel's material. And according to Harrison, his material has a number of major environmental advantages. For a start, the kilns don't need to be run so hot. Magnesium carbonate converts readily to magnesium oxide at around 650 ˚C. This means that emissions of CO_2 from the energy used to fire kilns are roughly halved.

The roasting process for the manufacture of eco-cements produces more CO_2, but during setting and hardening, a process called carbonation reabsorbs [*sic, readsorbs*] most of this from the air. When conventional concrete made from Portland cement is fresh[,] water in the mix also slowly absorbs CO_2 from the atmosphere. This solution then reacts with the alkaline calcium-containing components in the concrete matrix to deposit calcium carbonate crystals, which reduce the strength of the concrete. But carbonation is quicker and more efficient in Harrison's endor[s]ement. Magnesium carbonate crystals are stronger than those of calcium carbonate, so they add to the material's strength.

If eco-cement is used to make porous materials like masonry blocks, virtually all the material will eventually carbonate, says Harrison. [“]A tonne of concrete can end up absorbing up to 0.4 tonnes of CO_2” he says, "equaling about 100 kilograms of carbon. The opportunities to use carbonation processes to sequester carbon from the air are just huge", says Harrison “It can take conventional cements centuries or even millennia to absorb as much as eco[-]cements can absorb in just a few months”. This means that eco-cements quietly carbonating in a tower block could be performing much the same atmospheric function as a growing tree. And if eco-cements gained a foothold in our cities, they could immediately reduce the cement industry's contribution to global warming, reabsorbing much of what was emitted in their creation. By directly replacing Portland cement with his eco-cement, Harrison estimates that we could eliminate over a billion tonnes of CO_2 each year.

The idea is “a world first,” says Fred Glasser of the University of Aberdeen's chemistry department, one of the leading authorities on cement technologies. And eco-concrete has another way of proving its greenhouse-friendly status. The material has huge potential for incorporating all sorts of waste matter, including carbon-based organic wastes that would otherwise rot or burn and release CO_2 into the air. Adding inert waste such as fly ash to cement is routine in the industry. But for Portland cement there are strict limits. Because the cement is alkaline, mixtures can react with aggregate to crack the concrete or make it brittle, sometimes causing failure. “Magnesium cements are much less alkaline, and the potential problems are far less,” says Glasser, who believes this could be one key to their eventual widespread use.

"Organic waste from rice husks to sawdust, plastics and rubbers can all be incorporated as a bulking material in magnesium cement without it losing significant strength," says Harrison, “thus turning the cement in buildings, bridges and so on, into significant stores of carbon. We have made bricks that are over 90% ash,” he says, “We can probably get three to four times more waste into our cement than Portland cement and would also massively reduce the amount of cement needed in the first place.”

“His magnesium based cements may not meet every requirement,” he admits, "You might not want to replace Portland cement entirely for, say, bridge beams. But Harrison reckons magnesium cements could eventually replace 80% of cement. This move wouldn't come cheap. Prime sources of magnesium carbonate, such as magnesite and dolomite, cost more to mine than calcium carbonate. But the price should fall with economies of scale, says Glasser. Harrison has already gone into manufacture. He sold his first eco[-]cement bricks for a commercial building project in May this year. But he fears the cost of maintaining his patents could force him out of business before it really gets going.

“The main problem,” says Glasser, “is that the building materials industry is intensely conservative—it prefers what it knows, Portland cement. Engineers are familiar with its mechanical properties. And of course, Portland cement is cheap. It may guzzle energy like there is no tomorrow, but a couple of dollars will buy you as much of the stuff as you can carry away from a hardware store. The market for Portland cement is so vast that it is difficult to see magnesium cements making much of an inroad in the next 10 years.” Says Glasser, “But perhaps, as the world tries to think up new ways of cutting back on its emissions of CO_2, eco-cement may have its day. Our burning of fossil fuels is force-feeding Earth's atmosphere with CO_2 at a rate that vegetation can no longer absorb. The logical way out is to accelerate the formation of carbonate with our own man-made rocks. What better way” says Harrison, “than in cement?”

Having provided you with some background on the range of alternatives to Portland cement technology, we are now ready to discuss specific commercial products that are available today or are under development. We have classified these into subsections according to cement chemistry and will start with the older formulations and proceed to newer developments—although it is hard to separate the old and the new, as many old secrets are being rediscovered.

Commercial Products: Lime

Rosendale Cement. Lime is the primary ingredient in Rosendale Cement, a time-tested recipe with a long and storied history in major American construction projects.[192] For most of the nation's first century and a half, Rosendale cement was particularly valued as a quick-setting mortar compatible with the accelerated pace of the Industrial Revolution.

In 2004, more than thirty years after the last of the original mining operations closed, Edison Coatings, Inc. of Plainville, Connecticut (800-697-8055; www.rosendalecement.net and www.edisoncoatings.com) reopened a mine and resumed production of this product for use in restoration of historic structures and monuments. The company also supplies an entire line of environmentally friendly finishing products for masonry and other mineral-based surfaces, including breathable coatings.

Rosendale natural cement is hydraulic cement (meaning that it sets under water) and is made with dolomitic limestone having higher clay content than building lime, which is not hydraulic. The production process is explained further on the company website:[193]

> *Lime* and *Natural Cement* are both produced by heating limestone to approximately 900 to 1100 °C [1650 to 2000 °F], at which point carbon dioxide bound within the stone is released. In the production of lime, the burnt material is *quicklime*, which is then mixed with water to make building lime, also referred to as *hydrated lime,* or as *lime putty* if excess water is used. The process of hydrating quicklime is *slaking*, and when quicklime is slaked, it crumbles to a fine particle size. The burnt natural cement rock does not slake when mixed with water, however. Instead, it must be crushed into a powder before use. The resulting powder is *natural cement,* which will set when mixed with water, and hardens through a process of cement hydration.
>
> When lime is used in masonry mortar and renders, it does not set due to being mixed with water, but rather, must react with carbon dioxide in the

[192] As per http://www.rosendalecement.net/html/history_of_rosendale_cement.html: "Natural Cement was used in the construction of some of the most enduring landmarks of the nation: The Brooklyn Bridge, the pedestal of the Statue of Liberty, the wings of the U.S. Capitol, the lower 152' of the Washington Monument, the Croton Aqueduct and dams, the Pennsylvania Railroad tunnels, the New York State Thruway, and thousands of other public works projects."
[193] See http://www.rosendalecement.net/html/rosendale_cement_chemistry.html.

air in order to cure and harden. This is a slow process, often requiring weeks or months to build significant initial strength.

Mike Edison, chemical engineer, Founder and President of Edison Coatings, explained to us that the primary cementing phase is dicalcium silicate, but that some aluminates are also involved in the bonding action.

Commercial Products: Magnesium Oxychloride

Flooring. We will start by mentioning flooring mainly because it is the oldest modern industrial application of magnesium oxychloride. There remains a small market in the U.S. and we found an architectural web page[194] listing a large number of companies supposedly in the market, although representatives of three of them that we called denied that they made such a thing. However a correspondent sent us a January 2000 conference proceeding[195] containing a nice review from a European perspective of the history, properties and market for magnesium oxychloride flooring, including confirmation that there is a market in the United States. We quote from this presentation by the top scientists for a Greek supplier of raw materials for magnesia-based cements.

In 1867 a French engineer named Stanislas Sorel discovered that when active magnesium oxide is added to a solution of magnesium chloride an exothermic reaction takes place and forms magnesium oxychloride, which appears like an extremely strong and hard block. Investigating further the properties of magnesium oxychloride he realized that, apart from its extraordinary endurance in mechanical strength, it also had an excellent bonding capacity, enabling the binding of various organic and inorganic aggregates. The first aggregate used was wood shavings (sawdust) and the initial commercial application of this invention was in the construction of flooring, which became known as Sorel cement floor. The first floors were laid during the 1890's for use in residential and industrial constructions under the name of "xylolith" (wood stone) or "parquet sans joints" (jointless floor). Further technical developments followed over the years in terms of the aggregates and additives, as well as the solutions of magnesium salts used, enlarging the spectrum of application of the magnesia cement.

> Sorel cement floors are functional because:
> · They have excellent adhesion and they can be quickly laid on any substrate, new or old
> · They are self leveling
> · Their thickness can be from less than 5 mm to over 5 cm
> · They acquire high early strength
> · They are uniform in their mass and jointless
> · They do not need wet curing
> · They require low maintenance and are quickly and simply repaired.

[194] See http://www.arcat.com/divs/sec/sec09673.shtml.

[195] M. Halaris and Th. Zampetakis, "Magnesia Cements: Over a Hundred Years Old but Still Novel," presentation at Industrial Minerals Annual Forum - Minerals in Architectural Markets, January 11, 2000. The authors are affiliated with the Greek magnesium chemicals company, Grecian Magnesite S.A.

The performance / specifications points of view:
Sorel cement floors have controlled performance because:
· They are highly resistant to shocks, can receive heavy weight and are practically weariless, because of their high compression and flexion strength as well as abrasion resistance
· They are resistant to fuels, solvents, grease, non acidic oils and paints
· They have excellent electrical and low thermal conductivity
· They are incombustible and fire resistant

The ecological and comfort point of view:
Sorel cement floors are ecological because:
· They are non toxic, inorganic, dust free and odorless
· They have good acoustical properties
· Their surface is smooth, warm and non-slippery
· They present insecticide properties and they discourage bacteria and fungi growth
· They are available in a wide variety of colors

Precautions and Limitations
MOC is corrosive therefore metallic parts have to be protected, when they adjoin with it. However its major limitation comes from its non-resistance to prolonged contact with water. Consequently it cannot be installed in exterior constructions and also in areas, which need repeated water flow cleaning.

Sorel Cement Floor Applications
As we said before Sorel cement floors have been initially used in residential and industrial constructions. It is worth mentioning that the floors of the first wagons of the Paris Metro were laid with Sorel cement, thanks to their resistance in shocks and continual vibration. Another specialized application was in shipbuilding for the interior decks of war and merchant vessels. Today Sorel cement industrial floors constitute an economical solution for a wide range of industrial sectors, including automotive, aerospace, electrical and mechanical, printing, electronics, pharmaceutical, plastics, clothing and textile, general warehouses, and furniture

Sorel Cement Floor Markets
Central Europe constitutes the main market, where Germany has been traditionally the leader. The average size of the European market for the last decade, is estimated at 3.5 million m2/annum, with a peak period of 4.5 million m^2/annum in 1991-1993. Tough competition prevails in Sorel cement floors markets, which causes pressure on market prices. Competition comes both from internal antagonism between Sorel cement floors laying companies fighting for market share and also from less expensive floors. As a consequence market prices have dropped during the last years at a current average level of around 12 EUR/m2. Moreover, for large sites, prices below 10 EUR/m2 have been reported. There is a niche market for Sorel cement floors in the US for residential as well as commercial and industrial flooring. This market is estimated at 1.5 million m^2/annum. Price levels are reported to be in the range of 20

> USD/m^2, which is substantially higher, compared to the prices applied in Europe.

Finally, note that we describe elsewhere (chapter 11) George's slab protocol in which magnesium oxychloride sheeting is applied on top of Portland cement concrete because of its much lower electrical conductivity.

Air krete® Thermal Insulation. Air krete® (315-834-6609; www.airkrete .com) is a blown-in insulating material with a calcium magnesium oxychloride silicate composition. It combines all the advantages of magnesia-based cement with aeration and spray-in-place convenience. Developed in the early 1980s,[196] it is a natural, nontoxic alternative to modern spray-in-place open and closed cell foams that creates the same solid barrier. Like other spray-in-place foams, air krete® fills all air gaps within the wall cavity, thereby disallowing cold air from infiltrating and heat from being lost in winter. This keeps the temperatures more uniform throughout the house. The material does not expand, shrink or settle (dimensional stability- ASTM C 951: zero shrinkage).[197] Further test results can be found on the company website.

Air krete® is made with magnesium oxide, calcium chloride, talc, a foaming agent and water. It contains no formaldehyde. Chemically sensitive individuals tolerate this product, but as with all materials, they should test a sample first for tolerance before having it installed.

Air krete® is hygroscopic, thereby regulating indoor air humidity and providing healthy, comfortable indoor air. It contains no potentially carcinogenic fibers. It also repels insects.

Air krete® is resistant to mold growth:

> A study [was conducted] using a microbial test protocol following the requirements of ASTM Guideline D 6329-98 (1). Results show that the "Air krete® Insulation Sample" was resistant to mold growth at both 75% and 95% relative humidities. Neither test molds were found to amplify in the materials at either humidity.[197]

Air krete® is fire- and sound-proof:

> Report on surface burning characteristics determined by ASTM-E 84. The normal 10 minute test was extended to 30 minutes with the following results:[198]

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[196] Air Krete Inc. patented a wide range of possible formulations:
(a) Donald Thomson and R. Keene Christopher, World Patent No. 8,400,891: "Foam insulation and a process for producing the same and insulating the cavities of structures." Application filed August 29, 1983; granted March 15, 1984.
(b) R. Keene Christopher and Donald Thomson, United States Patent No. 4,731,389: "Foam insulation and process for preparing the same." Application filed November 14, 1985; granted March 15, 1988.

[197] See http://web.mac.com/airkrete/iWeb/Site/products.html.

[198] See http://www.airkrete.com/testresults.php.

Flamespread Factor: 0
Fuel Contributed Factor: 0
Smoke Density Factor: 0

Air krete® has an excellent R-value of 3.9 per inch at 75 ˚F, according to C-518.76.[197] For wood-frame construction this can result in an energy savings of up to 30-50% over fiberglass.[199] Like all thick, breathable insulations mentioned in this manual, the cost savings over the years helps the average homeowner pay for the increased cost of insulation.

Air krete® is also environmentally sound, in that it is nontoxic and contains no formaldehyde. CFCs are not used in its manufacture. It is also fully recyclable and actually enhances soils in landfill by returning magnesium oxide as a mineral.

Lastly, it is essential that Air krete® be applied correctly to achieve the benefits of this product. Otherwise, if not installed correctly, it can become brittle. According to president, CEO and co-inventor, R. Keene Christopher, research is ongoing at the company to develop less rigid and friable magnesia-based foams that have all the beneficial properties of Air krete®. (Also note in the next subsection that corresponding products based on magnesium phosphate have been developed elsewhere.)

GreenKrete Building Systems. GreenKrete, a young company in Iowa, manufactures building blocks, plaster, roofing tile, and loose-fill thermal insulation using plant fibers and magnesium oxychloride cement. Their products and how to build with them are covered in detail beginning with section 8.10.

Sheeting. Several companies are importing structural boards from China composed of fiberglass-reinforced magnesium oxychloride with fillers and additives to impart moisture resistance. These ready-made building boards that replace wood products will soon be manufactured in this country and possibly Mexico. They have the capacity to revolutionize the building industry by offering a breathable, nontoxic, mold-free alternative to wood sheathing, wallboard and decking. These products are described separately in section 8.11, and chapter 10 describes George's system to build with them.

Commercial Products: Magnesium Oxysulfate

Tectum Acoustic Wall, Ceiling, and Roof Deck Panels. For nearly sixty years the Tectum Corporation of Newark, Ohio (888-977-9691; www.tectum.com) has been manufacturing lightweight (320 kg/m^3) sound-absorbing panels using an environmentally friendly process based on magnesium oxysulfate chemistry and long fibers of aspen wood. The Forest Products Journal reported the product composition to be as follows:

[199] See http://www.brandinsulation.com/faq.asp.

> The binder for Tectum panels contains magnesium oxide, sodium silicate, magnesium sulfate, calcium carbonate, and water. Finished panels are 44% wood fiber, 25% magnesium oxide, 16% sodium silicate, and 15% other materials. Because the curing reaction is exothermic, little energy is required to produce the panels.[200]

The Tectum panels are available in thicknesses of one to two inches and offer a healthy alternative to products containing mineral wool that dominate the acoustical panel market. In Austria and Germany these "magnesite-bound wood wool" panels have been manufactured since the 1920s, and the technology was first patented back in 1909. Though sold for interior use in the U.S., the Tectum panels are extremely durable even in moist environments and have been used, for example, above swimming pools. In fact the company Heraklith AG manufactures what appears to be an extremely similar product and sells it in Europe for both interior and exterior use, touting its excellent fire resistance, thermal insulating and heat-storing characteristics, high vapor permeability, and being an "ideal base for rendering."[201]

Commercial Products: Magnesium Phosphate

Practical magnesium phosphate cements are formed by reaction of magnesium oxide with a water-soluble acid phosphate salt of ammonium, aluminum or potassium. A nice review of the options is given in a section in Mark Shand's recent book, *The Chemistry and Technology of Magnesia*.[202] Argonne National Laboratory scientist and Ceramicrete® inventor Arun Wagh's treatise, *Chemically Bonded Phosphate Ceramics: Twenty-First Century Materials with Diverse Applications*, gives a detailed presentation of the state of the art in 2004.[203]

Grancrete Inc. Grancrete®, a spray-on structural cement, was developed by scientists at Argonne National Laboratory and Casa Grande LLC (now Grancrete Inc.). The patented Ceramicrete® technology[204] was originally developed to block neutron radiation transmission and enclose nuclear waste. A paper released by Argonne National Laboratory (www.anl.gov; search under "Grancrete"), has described Grancrete® as:

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[200] *Forest Products Journal* 48(11/12): 13, 1998, as referenced at http://www.fpl.fs.fed.us/tmu/resources/documents/nltr/nltr0199.htm.

[201] See http://www.skanda-uk.com/heraklithProducts.htm#HBM and www.heraklith.com. The Heraklith AG product has a density of 300 kg/m^3 and is available in thicknesses of 15 to 100 millimeters (⅝ inch up to 4 inches).

[202] Mark A. Shand, *The Chemistry and Technology of Magnesia*, John Wiley & Sons, Inc., Hoboken, New Jersey (2006), pp. 235-238.

[203] Arun S. Wagh, *Chemically Bonded Phosphate Ceramics: Twenty-First Century Materials with Diverse Applications*, Elsevier, San Diego, California (2004).

[204] A. S. Wagh, D. Singh, and S.-Y. Jeong, United States. Patent No. 5,830,815: "Method of waste stabilization via chemically bonded phosphate ceramics." Application filed March 18, 1996, granted November 3, 1998.

> A tough new ceramic material that is twice as strong as concrete [that] may be the key to providing high-quality, low-cost housing throughout the developing nations.
>
> According to experiments, Grancrete is stronger than concrete, is fire-resistant and can withstand both tropical and sub-freezing temperatures, making it ideal for a broad range of geographical locations.

Grancrete® (919-597-2500; www.grancrete.net) is made in Research Triangle Park, North Carolina from magnesium oxide and potassium dihydrogen phosphate. It adheres to porous surfaces (cement, brick, stone, wood) and even rebar by chemically bonding with the substrate. It actually bonds to steel rather than encapsulating it, as Portland cement does, according to the FAQ page on the company's website. Grancrete® is twenty percent lighter than concrete with a high compressive and flexural strength. It has a compression rating between 6,000 and 8,000 psi and does not expand or contract.

Grancrete® is supplied as a powder that is simply mixed with water. It can be troweled, poured or sprayed on and is self-leveling. It cures within 15 to 20 minutes and can be colored using colored mineral products. Grancrete® has undergone ASTM testing and is fire-rated to withstand 2,700 °F for four hours, and 2,100 °F for up to three days. The new Grancrete® HFR (High Fire Resistant) has the highest fire and heat tolerance rating of their product line.[205]

Grancrete® is waterproof and cures under water, but is moisture vapor permeable. The company is applying for a "green" label that will enable it to be pulverized and mixed with soil for disposal, making it very environmentally sustainable. The product is durable and expected to last more one hundred years. It is best to lay electrical conduit and plumbing before pouring Grancrete, as one must use a diamond-tipped drill or saw to route the material after it sets.

Grancrete® is nontoxic and testing shows it does not leach out any materials. This makes it beneficial for chemically-sensitive homeowners.

With only two days of training, two men can build a nontoxic durable home from Grancrete® in two days that is ready to be occupied by the end of the second day. This is because the material cures within two to four hours, not many hours or days like regular concrete. The material is several times less expensive than currently used products and has been extensively field-tested for structural properties. It provides a healthy, affordable alternative to non-breathable building materials, particularly when used in conjunction with a locally available natural fiber core. Grancrete® is often applied to expanded polystyrene cores, but the Argonne inventor, Dr. Arun Wagh, "suggests simpler walls, such as woven fiber mats, also work well (for the cores) and further reduce the raw materials required."[206]

[205] See http://www.grancrete.net/products/index.cfm.
[206] See "Grancrete™ Spray-On Structural Cement and Rapid Construction Process for Low-Cost Housing," posted at http://www.grancrete.net/products/index.cfm.

Building biologists would certainly recommend a woven core to avoid using non-breathable petroleum-based products such as expanded polystyrene. Natural magnesium oxide applied over a cellulose core, or alternatively, using Air Krete® brand magnesium oxide-based foam (see below), are excellent choices.

Bindan Corporation. We turn next to the Bindan Corporation of Chicago (630-734-0277; www.bindancorp.com), a second magnesium phosphate cement supplier that licenses Argonne National Laboratory's Ceramicrete® technology. Bindan makes twelve different products. Just add water and they are ready to go. According to George, their cements and concretes are some of the strongest ever tested.

Bindan products can be used for concrete repair, underlayment and terrazzo applications. Bindan also makes one of the best products for pouring floors. According to the company website, their cement sets fast, does not outgas, bonds without priming agents, has no special curing needs, and can be used both indoors and outdoors. It has zero shrinkage and rapid strength gain, is fireproof, freeze/thaw resistant, and can be used in all climates, hot and cold.

The cost of Bindan magnesium phosphate cement is approximately $30 per 50-pound bag. This compares to $5 per bag for Portland cement, but the wide variety of indigenous rock, plant and wood fibers, and other cellulose granules that can be added quickly amortize this discrepancy in cost by diluting the basic cement material by up to about 95% of the concrete mix.

CeraTech Inc. The products of a third manufacturer, CeraTech® (888-341-2600; www.ceratechinc.com), are similarly magnesium phosphate cements that are activated by water. Like the others, these are high early strength self-leveling cements for horizontal surfaces that can also be troweled onto sloped surfaces. They can also be used as a parging material for vertical and overhead surfaces.

Ceramic Cement Corporation, subsidiary of Co-Operations Inc. Finally, in a further effort to resolve the raw material cost problem with magnesia-based cements, Co-Operations Inc., a Seattle-based research and development company, has recently been successful in identifying large, worldwide sources of recyclable magnesium oxides that were inadvertently produced as a by-product of the industrial revolution, and they are also working to develop a significantly less expensive, manure-based process for producing the necessary phosphate minerals needed for these innovative ceramic cements. This company has also successfully tested and applied for a patent on a phosphate-bonded radiation shielding formula[207] that promises a wide variety of uses, with possibilities ranging from replacing the lead shielding used in medical and x-ray facilities to nuclear and hazardous waste containment, as well as safer computer and cell phone casings.

[207] Judd Douglas Hamilton, United States Patent Application Publication No. 2007/0102672 A1: "Ceramic Radiation shielding material and method of preparation." Published May 10, 2007, based on Appl. No.11/441,833, filed May 26, 2006.

Ceramic Cement Research Institute. The Ceramic Cement Research Institute (479-899-7053; teslastones@gmail.com) is the new venture of Jonathan Hampton, a former builder and independent researcher based in Bentonville, Arkansas. Hampton has developed a nontoxic, spray-in-place magnesium phosphate-based foam for thermal insulation having excellent mechanical properties. However as of October 2007 there were no definite plans for commercialization.

Hampton has several ongoing projects involving magnesia-based cements, including new sheetrock replacement and stucco products that will be initially commercialized in the United Kingdom by a consortium of companies. He told us that this new process marries magnesium oxychloride, magnesium phosphate, and sodium silicate bonding technologies.

When construction is complete, the Ceramic Cement Research Institute will be a place with facilities for contractors and artisans to spend a week and learn how to work with magnesia-based cements. Hampton notes that unlike Portland cement, which "has a large window of stupid" allowing one to get a viable product from a mix even when mistakes are made, magnesia-based cements are less forgiving, requiring some specialized skills and experience. (Such training will also be offered by George Swanson.)

Reactive Magnesia to Prepare Your Own Mixes

If you want to prepare your own mixes, magnesium oxide is also available in bags for as little as $9 per 50 pound bag from several other sources (see list of websites in the Resources sidebar) Unlike all other bag products described in this section, these products require either liquid fertilizer or special brine "reactors" to harden them into concrete and are especially useful for binding non-load-bearing straw/clay and wood fiber/clay mixes for building construction.

Resources

This subsection contains online resources for further information pertinent to healthy alternative cements.

General or Miscellaneous

www.geoswan.com and http://www.geoswan.com/html/mgo2424.html and http://www.geoswan.com/slideshow/index.htm (Austin, Texas builder, consultant, distributor, and author George Swanson's home page, and pages dedicated to MgO, including a slide show on a recent straw-clay/MgO project.

www.tececo.com and http://www.laleva.cc/environment/rainforest.html (Australian manufacturer of magnesium oxide-based "Eco-cement")

www.geopolymer.org (French institute offering a wealth of information on alternative cements and more)

www.premierchemicals.com (Ohio supplier of magnesium-containing raw materials; search under "Library" section, then "Magnesia Cements" for an article of interest.)

http://minerals.usgs.gov/minerals/pubs/commodity/magnesium/ (USGS commodity statistics and information about magnesium-containing minerals)

Lime

www.rosendalecement.net and www.edisoncoatings.com
(Connecticut-based manufacturer of Rosendale natural cement)

Magnesium Oxychloride

www.airkrete.com (New York-based calcium magnesium oxychloride silicate spray-in foam insulation)

www.greenkrete.com (Iowa-based manufacturer of low-density fiber-cement building blocks, plaster, stucco, roof tile, and loose-fill insulation, all made with plant fibers and magnesium oxychloride)

www.chemicalceramics.com (Illinois-based licensor of "Chinacrete" technology)

(Sheeting products from several suppliers are listed below.)

Magnesium Oxychloride Sheeting Products

www.strongenviroboard.com (Shanghai, China-based manufacturer, with offices in Houston, Texas; distributed by George Swanson through substanceproducts.com)
www.dragonboard.com (Astoria, New York-based importer; distributed by George Swanson through substanceproducts.com)
www.mag-board.com (Nevada-based importer)
www.magnesiacore.com (Ontario-based importer with emphasis on the commercial market)
www.greeneboard.com (Florida-based importer; distributed by George Swanson through substanceproducts.com)
www.versaboard.com (Washington-based importer)
www.magnumbp.com (Florida-based importer)

Magnesium Phosphate

www.anl.gov (Argonne National Laboratory. Search under "Ceramicrete")
www.grancrete.net (North Carolina manufacturer of bag products, Argonne National Laboratory licensee)
www.bindancorp.com (Chicago-based manufacturer of twelve products, Argonne National Laboratory licensee)
www.ceratechinc.com (Virginia manufacturer of products for road & bridge repair)
www.ceramiccementcorp.com (Seattle research firm developing low-cost cements, including products to shield ionizing and microwave radiation)
www.ecocreto.com (Texas manufacturer of "Magnacrete" bonding additive for creating pervious concrete)
www.lithistone.com (Colorado manufacturer of custom sinks, countertops and vanities, architectural stonework)
www.bonesolutionsinc.com (Texas manufacturer of "OsteoCrete" bone adhesive)

Reactive Magnesia to Prepare Your Own Mixes

www.baymag.com (Calgary, Canada-based low-cost supplier)

Now that we have introduced you to alternative cements, the next two sections will each be devoted to a class of composite building envelope materials based on magnesia. First, in section 8.10, we will describe a new generation of low-density fiber-cement blocks in which Portland cement is replaced with magnesium oxychloride. Then, in section 8.11, we present a new, breathable option in lightweight, thin-wall construction, specifically magnesium oxychloride ("MgO/Cl") "low-tech" composite boards that are beneficially and affordably substituted for drywall, oriented strand board (OSB) or plywood.

8.10 Low-Density Fiber-Cement, Made with Alternative Cement

A promising development in the natural building material movement is the revival of a twelve hundred year old recipe for blocks made with plant fiber and natural cement. An innovation is occurring in the heart of the Midwest by two entrepreneurs, Ron Bessette, a French-Canadian, and Kurt Kleinschnitz, an American, who have pioneered the development of a bio-composite fiber and natural cement solid masonry block. Both men have experience in the building trade, and together they have created GreenKrete Building Systems (866-306-0939, www.greenkrete.com), based in Fairfield, Iowa. Bessette and Kleinschnitz have innovated upon the original recipe, creating a load-bearing building block suitable for the US market.

Company president Ron Bessette describes the product line in the following way:

> The raw materials that make up our blocks are the key to our success: renewable plant fibers such as industrial hemp, kenaf and rice as well as non-toxic alternative cements incorporating natural pozzolans, creating a "fibercrete" building component similar to the European cast-in-place "hempcrete." The main difference is that our material has structural capability, independent of the traditional post & beam reinforcement. GreenKrete is the first manufacturer to offer a mass-produced bio-composite load-bearing masonry building block using a sustainably grown plant fiber as the main aggregate.

Figure 22. Home built with GreenBlok®. (Photo courtesy of GreenKrete Building Systems.)

GreenKrete's product line features materials for residential and commercial construction that are sustainable, insulating, and breathable. Compression of the traditional fiber and cement mixture allows the blocks to be load-bearing. They are produced from renewable ingredients that can be locally grown. For now, some of the raw materials are imported from Canada and other countries. GreenKrete's products are adaptable to both warm and cold climates. Homes built with GreenKrete® are healthy for occupants because they provide a quiet, comfortable, energy-efficient indoor environment without mold or outgassing.

The cement used in GreenKrete® is magnesium oxide based, and the blocks are ready made for easy use by builders. Since GreenKrete does not use Portland cement, which emits vast amounts of greenhouse gases when made, their blocks are carbon neutral. The blocks therefore contain low embodied energy and are ecologically sound.

Furthermore, the fiber is grown without chemicals, making GreenKrete one of the first companies to use organic crops in its formulation of building materials. Their blocks contain no fly ash or toxic chemicals, making them an ideal choice for chemically-sensitive home owners. They are also fully breathable and able to dry out if any moisture intrusion occurs. Mold is therefore not a problem.

GreenKrete Building Systems is licensed by Natural Home Building Systems, LLC, and has manufacturing and distribution facilities in southeast Iowa. Beyond serving markets located within the central Midwest, the company plans to "license small eco-factories that will operate independently for a specific territory," according to Bessette and Kleinschnitz. GreenKrete's products have passed preliminary structural testing and meet and surpass requirements set by the International Building Code. They are scheduled for formal testing by certified labs and expect International Code Council (ICC) certification by the end of 2008.

The developers state that they are "aware of the failings in the construction industry as regards to healthy interiors, [lack of] sustainable materials and the environment. Our goal is to create products that solve these problems at their source without compromising nature."

The products are based upon simple principles, discussed repeatedly in this manual, that mimic the way the natural world works and have stood the test of time. Many buildings throughout the world use plant fiber and natural cement and have existed over centuries with no structural issues, rotting or interior toxicity.

Historically, the original formula that GreenKrete® is based upon, hemp and lime, was used as far back as the reign of Charlemagne in the late eighth century. Homes, churches and bridges were built throughout Europe with a stone or timber frame. The voids were filled with non-load-bearing hemp and lime "wattle" covered in plaster. This mixture is highly durable, with one home currently in southern France still standing after almost 600 years. GreenKrete's manufacturing process, however, compresses the fiber and cement, creating a load-bearing stand-alone block.

GreenKrete's product line includes blocks for foundation and wall construction, molding for interior and exterior ornamental and trim, natural plasters and stuccos, and in-wall radiant heating and cooling systems.

Figure 23. GreenBlok® bio-composite block. (Photo courtesy of GreenKrete Building Systems.)

Figure 24. GreenBlok® on the job site. (Photo courtesy of GreenKrete Building Systems.)

GreenBlok®, the primary component in the company's product line, is similar to autoclaved aerated concrete in that it is a solid block and is constructed using mortar. It is used for both interior and exterior walls, below and above grade. While GreenBlok® is structurally load-bearing for buildings up to three stories tall, it is also available for post and beam construction, as the original recipe is used in Europe.

From the company's website:

> GreenKrete® offers many benefits compared to conventional construction methods: natural & non-toxic, breathable walls, good thermal insulation, excellent sound insulation, lightweight, resistant to fire, rodents, termites, mold and mildew. It can be drilled, sawed, nailed, or screwed into just like wood.

We discuss the use of GreenKrete® on the job site in section 9.5.

Additional features include the following:

> Lightweight. Easy to handle, the material is approximately one half the weight of conventional concrete.
>
> Load-bearing. Engineered to facilitate single to three-story construction without additional reinforcement.
>
> Insulating. Energy efficient and thermally non-conductive, the blocks require no additional insulation even in the most extreme climates.
>
> Soundproof. The fiber material is extremely sound absorptive as well as being thick and solid in its application.
>
> Fireproof. The cement content prevents ignition of the material.
>
> Insect-proof. Because of its inert characteristic and cementitious constitution, there is no food for insects to be attracted to.
>
> Water-resistant. There is no deterioration of the characteristics of the material when exposed to water.

According to Ron Bessette:

> Owners love this building system. The thickness and mass of the walls give substance to the home or commercial building. The thick solid walls create silence in the building, even in an urban setting. The high insulative value translates into very low utility bills. The integrated radiant heating and cooling system keeps the indoor temperature constant without blowing air and the noise of ventilating systems. The natural clay interior wall coating regulates the indoor humidity, automatically keeping it in the human comfort range winter and summer. The natural stucco finish on the outside of the house keeps out water and rain, but permits the escape of water vapor, preventing any buildup of moisture which can lead to mold and rotting in conventional construction. And the material is insect and pest resistant. In Europe, quality homes built of natural cements and plant fiber, comparable to GreenKrete®, have been built for over a thousand years—and this durable system has stood the test of time. These blocks will produce a healthy home. And the cost of GreenKrete® blocks is competitive—meaning the house will be affordable.

> The GreenKrete® building block system makes architects and engineers happy. It should meet all applicable codes and standards for construction. It is forgiving, easy to use, and affordable, and in most applications will not increase construction costs for a project. It is a high quality product, but also easy to work with. It is anticipated that certification agencies for green construction, such as LEED, will rate the material highly.
>
> The GreenKrete® building block system is ideal for builders. These masonry blocks—the same volume of a cinderblock, and about the same weight—let a building go up incredibly fast. The blocks are both structural and insulating. The builder simply uses conventional thin-set mortar. Blocks can be cut to length using saws, or shaped with a router.
>
> Banded on one-ton pallets, blocks are easily inventoried, moved about on the site, and organized for construction. The exterior wall construction goes from five steps (framing, insulation, drywall, paint, exterior finish) to three (masonry and application of stucco and plaster).
>
> The GreenKrete® building block system is also great for our planet. It employs renewable plant fibers, currently grown with minimal agricultural inputs such as not using any pesticides or herbicides, for example. If an average size home were built with GreenKrete® block instead of conventional stud framing, it would save 4-5 acres of trees. The natural cements employed in the manufacture of the blocks have 2/3 of the embodied energy of a comparable concrete-based product.
>
> And they feel nice! A home built using the GreenKrete® system saves energy—this system is ideal for off-the-grid, solar-power, or alternative energy homes. There are no poisons in the blocks—no outgassing and no indoor air pollution. This building system should be superior in performance to adobe, straw bale, autoclave block, rammed earth, and other construction alternatives. Construction using the GreenKrete® system should have a longer life, less maintenance, less energy requirements, greater comfort, and lower overall expense of ownership.

One important outcome of the decision by GreenKrete®'s developers to use a mixture of plant fiber and natural cement is the creation of the same dynamic between the natural mineral and fiber that exists with other mineral/fiber building materials, such as the Durisol® cement-bonded wood fiber wall form. In a correspondence with Ron Bessette about this issue, he stated,

> There is the same thing happening in our material as with Durisol due to the interaction and complementary effects of the natural ingredients present. An advantage that we have is that we do not need to neutralize the negative effects of Portland cement as there is not any (Portland cement in GreenKrete®).

Furthermore, in contrast to so-called "concrete homes" made with Insulating Concrete Forms (ICF), GreenKrete® blocks, like Durisol® and Faswall®, have all the beneficial characteristics of the concrete home (superior thermal performance, thermal mass, durability, protection against heavy winds, acoustic properties) without the downsides. These downsides include: the hydrophilic (water intrusive) nature of concrete, which wicks, absorbs and holds liquid water; the high embodied energy needed to make concrete; the outgassing of water from concrete; the mold production in the layers between the concrete and the rigid foam insulation (in spite of what manufacturers say to the contrary — see below); the lack of breathability; and the use of petroleum-based foam as an insulator.

Finally, GreenKrete Building Systems is a pioneer in the use of in-wall radiant heat, rather than in-floor heat. Hydronic tubing carrying heated (or cooled) water is embedded in a plaster interior finish, providing even, health-promoting radiant heat (or cool) for the whole body of occupants rather than for the lower one-third of the body only, as with in-floor heat. This topic is covered in section 14.6.

GreenKrete® is a product worth considering as it meets all the characteristics of a Building Biology®-recommended building material. To contact the company's owners, call Ron Bessette or Kurt Kleinschnitz at 866-306-0939 or log on to www.greenkrete.com.

[We have also performed density and microstructural measurements of GreenBlok®. Results will be reported in a later version of this section. In brief, the mercury intrusion-derived pore-size distribution shown in Figure 27 (next section, page 158) indicates that, like other recommended wall materials in this chapter, GreenBlok® is highly breathable, i.e. both permeable to water vapor and capillary-open to enable escape of liquid water. −Ed.]

One other example of a low-density fiber-cement product made from alternative cement is the so-called "phosphate-bonded ceramic-wood composite." The USDA Forest Product Laboratories reports in their article on the subject:[208]

> Most of the work at the Argonne National Laboratory is based on the use of two types of binders. The first, Ceramicrete, has a resultant structure of $MgKPO_4 \cdot 6H_2O$ [Jeong and Wagh, 2003], which is formed by reacting magnesium oxide and monopotassium phosphate.
>
> The second binder is based on newberyite ($MgHPO_4 \cdot 3H_2O$), which is formed by the reaction of magnesium oxide with phosphoric acid solution [Wagh and Jeong, 2003]. … The phosphate binders are formed by acid–base aqueous reaction between a divalent or trivalent oxide and an acid phosphate or phosphoric acid.…
>
> Preliminary research and early prototypes indicate that phosphate-bonded products are at least as durable as current commercial wood–cement products and require little maintenance. Phosphate-bonded products have superior impact, thermal, and crack resistance and are more tolerant to weather fluctuation.

[208] See http://www.fpl.fs.fed.us/documnts/pdf2004/fpl_2004_laufenberg001.pdf.

8.11 Magnesium Oxychloride Composite Sheeting

In section 8.9 we deferred discussion of one of the most useful applications of magnesia-based cements until now. This section is devoted exclusively to magnesium oxychloride (MOC or MgO/Cl) cement-based composite sheeting or boards imported from China. As they have only been in the U.S. for less than ten years and there is no consensus on a generic name, we will call them "MgO/Cl" boards, or simply "MgO" boards when it comes to applications and we have already made clear that we are talking about this particular type of cement chemistry.

Introduction

In the North American industry and building trade, MgO/Cl boards are known as:

- Strong-Enviro Board® (866-640-7895; www.strongenviroboard.com)
- DragonBoard® (866-447-3232; www.dragonboard.com)
- MagBoard® (775-338-2252; www.mag-board.com)
- Magnesiacore® (905-794-1333; www.magnesiacore.com)
- Green E-Board® (561-932-0300; www.greeneboard.com)
- Versa-Board® (877-212-8221; www.versaboard.com)
- Magnum® Board (813-900-2957; www.magnumbp.com)

There is also a very good chance, if you have heard of them at all, that you have heard MgO/Cl boards being called simply "MgO boards" to signify the major ingredient is magnesia. However, as most of the magnesium oxide has reacted in the bonding process and is no longer present in the final product, this name may be misleading. Furthermore, as indicated in the last section, for nearly one hundred years there has existed a wood-cement composite sheeting technology based on magnesium *oxysulfate*, although these "MgO/S" products are not well known; within a few years completely different new products now being researched intensively in America using magnesium *phosphate* cements (MgO/P) may become available if raw material costs can be successfully brought down. So the term "MgO board" may become even less clear than it is now.

MgO/Cl board products are now available in the USA and Canada. These boards, available in eight standard U.S. thicknesses from ⅛ inch (3 mm) to ¾ inch (18 mm), can fully take the place of plywood, OSB and drywall in virtually all construction applications with little or no design change. (Often smaller thicknesses can be substituted due to superior mechanical properties compared to the products they replace.) Although they cost more than standard wallboard, MgO/Cl boards are cost-competitive with paperless wallboard, plywood and OSB. When you install MgO/Cl boards, reduced labor and material costs lead to overall cost savings of up to fifty percent. This is because a single MgO/Cl board with our recommended single coating of mineral stucco paint takes the place of multiple layered assemblies, typically including vapor barriers, mesh and layers of stucco. Insurance premiums are also lower due to fire and moisture resistance.

The fiber-reinforced boards typically meet all UL and ASTM requirements as a replacement for conventional sheeting materials. As of November 2007, three of the domestic companies (Versa-Board, MagBoard and DragonBoard) have applied for ICC (International Code Council) recognition, and the ICC has just decided (see below) to set standards for consideration of this class of product. In general, the DragonBoard Company has the highest level of documentation to date of all companies that import MgO/Cl boards.

These boards are causing quite a stir among building product industry insiders, according to Tim Faust of MagBoard (775-338-2252; www.mag-board.com). Faust built a small test home in hurricane-devastated Pass Christian, Mississippi for a study by the National Association of Home Builders Research Center (800-638-8556; www.nahbrc.org). He says the researchers are so impressed with his product that the project sponsors at the U.S. Department of Housing and Urban Development (HUD) have decided to name it one of their Top 10 Technologies for 2008. This list is published every February by HUD's Partnership for Advancing Technology in Housing (PATH) program.

Faust also told us that a name-brand manufacturer is interested in incorporating his board into their product line-up. *Wall and Ceiling* magazine included a five-page article about "MgO board" in their November 2007 issue,[209] and Faust says that other publications are contacting him regularly to interview him for feature articles about his product. One of the authors asked Faust why interest was so high in these boards, and his answer was, "They're afraid of wood" because of the potential for mold.

MgO/Cl boards are extremely affordable magnesia-based substitutes for drywall, oriented strand board (OSB) and plywood. They have been used extensively in Asia for decades. The products are currently made in over 900 plants in China, about fifty of which are large-scale operations, and in all but two cases are imported into North America through independent companies. MgO Partners, led by businessman Faust and Gordie Ritchie, a self-taught chemical engineer who prefers the description "panel maker," operate MagBoard, having designed their own manufacturing process. They share ownership of their brand new plant in China with their Chinese partner, MagBoard Building Products China. In 2008 the North American partners plan to open a plant in Atlanta to serve the southeastern U.S. market. Shanghai Beta Building Materials, Ltd., the Chinese manufacturer of Strong-Enviro Board®, also operates out of Houston under the name S.E.B. Beta Building Materials Co., Ltd. and plans to build a plant in the U.S. or Mexico and create an independent North American distribution network. A third company on American soil with a financial stake in a Chinese manufacturing plant is Canadian Reid Tynan's Versa-Board USA, Inc., headquartered in Redmond, Washington. Versa-Board is poised to begin importing product but is waiting for ICC recognition to do so.

Interest is rapidly growing in these alternative boards among domestic building product distributors, builders and testing officials as they work to find a mold-free alternative to wood-based products. In October 2007 the International Code

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[209] Robert Thomas, "MgO Board: A Primer on the Next Generation of Sheathing," *Walls and Ceilings*, November 2007, pp. ___. Available online at http://www.wconline.com/CDA/Archive/BNP_GUID_9-5-2006_A_10000000000000194720.

Council announced that they are going ahead and finalizing criteria for recognition of these magnesia-based sheeting products in the universal building code. Code consultant, Ted DeVit, told us that it typically takes 7 to 12 months for the ICC to evaluate each application from an individual manufacturer, so we anticipate the first ICC recognitions of MgO/Cl boards for specific applications to be published in 2008. Manufacturers who want to have their product recognized will have to pass regular factory inspections and meet strict quality control guidelines.

Product Description

As mentioned in the Introduction to this section, MgO/Cl boards are now available in various thicknesses ranging from ⅛ in. (3 mm) to ¾ in. (18 mm) for flooring, interior and exterior support walls and wall board, fascia, soffits, ceilings, columns, subfloors and roof decking. They are cost-competitive with paperless drywall and plywood products, with a delivered cost ranging from $15 to $45 per board, depending on quantity, thickness, structural quality and destination within the U.S.

Texture and Color. Boards from different manufacturers come in a wide variety of textures and colors. For versatility most of the boards come standard with one smooth side and a uniform machine-made texture on the other side. Variations include *[This information will be added in the published edition. –Ed.]* One brand offers a simulated wood grain texture for siding applications.

Sustainability. MgO/Cl boards are nontoxic, as they are made from all-natural, asbestos-free minerals without toxic chemical additives. All structural boards mentioned in this manual provide cost savings in energy consumption, which is important for the environment. The wall systems designed by George using this sheeting (see chapter 9) satisfy LEED requirements for insulation because they provide higher "whole wall" R-values than traditional fiberglass batt-filled wood frame walls. Compared to existing wood-frame structures, houses built with these materials consume half as much energy. This is notable in light of the fact that the U.S. Department of Energy estimates that buildings consume 48% of the total fossil fuel use in this country, and residences make up the majority of buildings. Furthermore, as indicated in section 8.9, the manufacture of magnesia-based cement uses substantially less energy and water than required to make Portland cement. Magnesium oxide-based boards can be recycled upon demolition or even composted, returning valuable minerals to the soil.

Choosing mineral-based products makes good ecological and economical sense. Plans are underway to build one or more plants in North America so that the boards will no longer need to be imported from China, which would help to satisfy the LEED requirement to use products that are produced within 500 miles of the job site.

Composition

The reader should appreciate that these MgO/Cl sheeting materials, though definitely not "high-tech," are accurately described as *composite* materials. The inorganic magnesia-based layer, composed of magnesium oxychloride and additives, is structurally reinforced with a fiberglass mesh,[210] and there may also be fillers that serve a variety of functions.[211] For example, Figure 25 illustrates the structure of one of George's favorite products, Strong-Enviro Board® , which is made both lighter in weight and sound-absorbing by inclusion of an "expanded" mineral filler similar to perlite. All reputable MgO/Cl boards also contain additives (see discussion below) that dramatically enhance the water resistance.

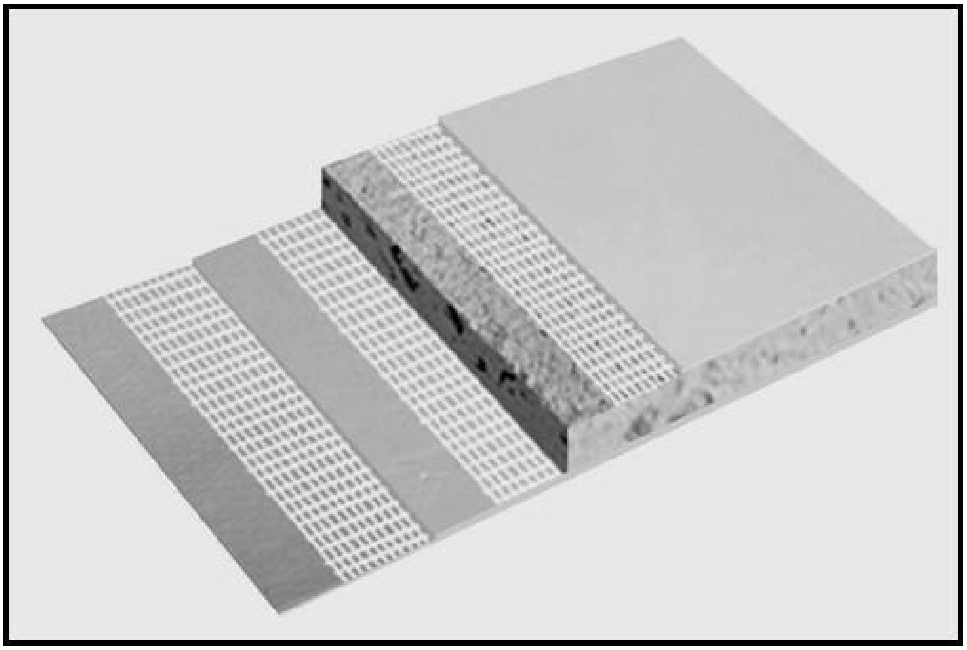

Figure 25. Cut-away photo showing the non-uniform layered structure of Strong-Enviro Board®. This sheet is covered with a thin magnesia-based (magnesium oxychloride and additives) finish coat on top and bottom. Similarly the thick inner layer is a magnesia-based mixture, but it is filled with a low-density, "expanded" mineral similar to perlite that makes the board lighter weight and enhances its sound absorption characteristics. The three layers are separated with a premium fiberglass mesh. (Photo courtesy of S.E.B. Beta Building Materials Co., Ltd., Houston, TX.)

By sifting through Material Safety Data Sheets and other product literature as well as talking with company representatives, we have learned that MgO/Cl boards sometimes contain many different components. The following is a very incomplete list—indeed we are guessing that those ingredients that companies

[210] According to MagBoard's Gordie Ritchie (personal communication with Wayne Federer, November 5, 2007), the fiberglass can either be topically applied or "keyed" (embedded) into the board. The latter is more expensive but much stronger because the mesh becomes an integral part of the board.

[211] The following thesis instructs us on the range of functions served by fillers: Thai lam Phuong, "The effect of fillers on the properties of inorganic phosphate cement (IPC)," Master's dissertation, Universiteit Gent, September 2004, available online at http:// phylares.vub.ac.be/Thesissen/2004%20Thai%20Lam%20Phuong.pdf.

reveal are most likely to be the ones that are either less important or readily detectable. Note that any additives to impart water resistance are *not* disclosed.

- Cellulose-containing fibers, such as wood chips or sawdust. (Products made for the Chinese market often contain bamboo or hemp.) These components, which are effectively mineralized during their incorporation to render them water- and fire-resistant, improve the mechanical/structural properties, as fibers are known to do in fiber-matrix composite materials.
- Talc, a very soft magnesium silicate mineral that is formed during the metamorphism of siliceous dolomite[212] (calcium magnesium carbonate) and presumably also of siliceous magnesite (magnesium carbonate). Talc alters the density and hardness of the board.
- Calcium carbonate (limestone), which coincidentally is a natural by-product of talc formation.[212]
- "Naturally occurring silicates" (unspecified). This could include either talc or other natural associations of the magnesium deposits.
- Aluminum sulfate. This could play a role in the cement chemistry, and if converted into aluminum oxide it will make the board harder.
- Nonwoven polyester mesh. This may serve a reinforcement function to supplement that provided by the fiberglass mesh.
- Wetting agents, defoamers, and fire retardants are usually not mentioned.

Physical Properties

In this subsection we describe various material properties that are available for MgO/Cl sheeting.

Density. Manufacturers report densities ranging from 850 to 1100 kg/m^3, with the lower values in this range being for boards containing a filler of expanded perlite-like rock. MgO/Cl sheeting is lightweight relative to Hardiboard® and similar materials (1150-1400 kg/m^3) but heavy relative to the thermally massive, thick-wall envelope materials described elsewhere in this chapter (350 to 750 kg/m^3).

Microstructure. In summer 2006 the Quantachrome Corporation generously performed nitrogen adsorption/desorption and mercury intrusion measurements on a sample of DragonBoard that we sent them. A standard B.E.T. model analysis of the nitrogen adsorption isotherm yielded an estimate of 15.3 m^2/g for the internal surface area. Porosimetry analysis indicated that the total open porosity of the sample was 50%, that is, half of the internal volume of the dry material was filled with air. The results for pore size distribution are presented a bit later, in the subsection on Breathability.

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[212] L. G. Berry and Brian Mason, *Mineralogy" Concepts, Descriptions, Determinations*, W. H. Freeman and Company, San Fransciso (1959), pp. 243-244.

We also examined a cross-section of the same sample under the scanning electron microscope (see). At a relatively low-power magnification of 100x (left-hand column of images) the porous nature was sometimes evident and sometimes not, i.e. the sample is quite heterogeneous on this scale. Higher magnifications (right-hand column of images) revealed finer porosity and microcrystalline structures that are consistent with the relatively high measured surface area and the presence of more than one crystalline phase. However, the upper right-hand image (500x) is a lot more representative of what we saw while moving around the sample than is the one in the lower right (10,000x).

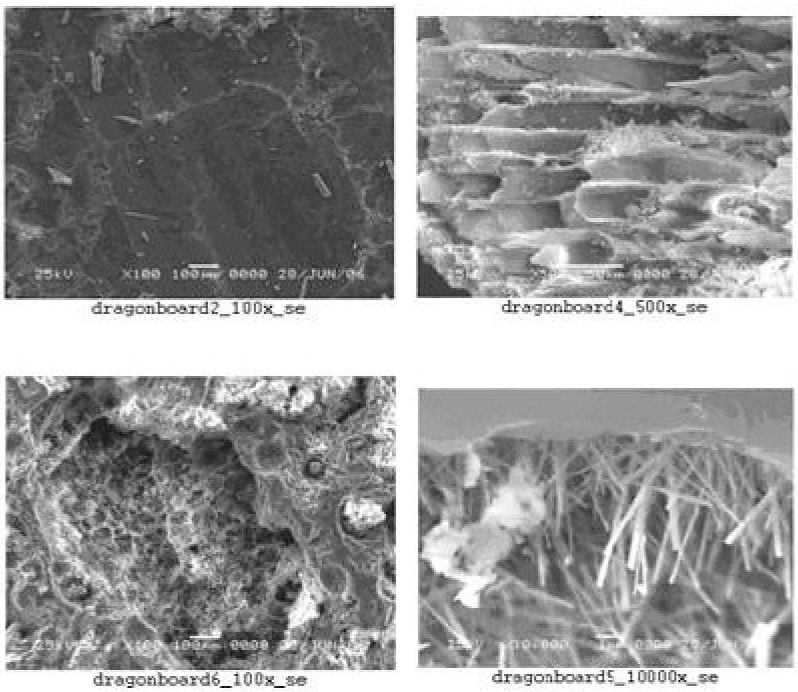

Figure 26. Cross-sectional scanning electron micrographs of a sample of Dragon-Board® MgO/Cl board.

Dimensional Stability. The following data reported[213] for Trilite RMS Board® by its Chinese manufacturer, Triple-Lite Incorporated, are representative of MgO/Cl sheeting products:

Thickness swelling	
after 24 hours immersion	0.2 %
after freeze/ thaw Test	-0.1 %
Moisture exposure elongation rate	< 0.9 %
Heat exposure deformation rate	< 0.2 %

Based on these data it is fair to say that MgO/Cl boards are shrink-resistant, offering less thermal expansion/contraction than steel.

Mechanical Strength. MgO/Cl boards vary greatly in their structural characteristics, depending on the type and amount of structural cloth layers

[213] See http://www.triliteboard.com/rmsboards.asp.

added, fillers and other additives used in the production. However the boards are often stronger than the materials they replace, allowing thinner sheets to be used. For example, Magnesiacore Inc. recommends the following substitutions:[214]

⅜ in. Magnesiacore® instead of ⅝ in. gypsum drywall
⅜ in. Magnesiacore® instead of ½ in. cement board [Hardiboard®]
½ in. Magnesiacore® instead of ⅝ in. particleboard

[The following needs to be written using data such as the following, converted into a single set of units. – Ed.]

DragonBoard®:[215]

Flexural modulus	.93 x 10^6 psi
Flexural strength	8935 psi
Shear strength	391 psi
Impact resistance	1.65 ft. lbs./in. of notch

Strong-Enviro Board®:[216]

Destroy load	740 N for 10 mm series
	1280 N for 18 mm series
Impact resistance	7 kJ/m^2 for 10 mm series
	19 kJ/m^2 for 18 mm series

Trilite RMS Board®:[213]

Bending strength	12.1 N/mm^2
Tensile strength	1.97 N/mm^2
Impact Strength	23 N/mm^2

Magnesiacore®:[226]

Modulus of elasticity	6045 N/mm^2
Flexibility	20.1 N/mm^2
Impact resistance	> 6 kJ/m^2

Thermal Conductivity. MgO/Cl sheeting is not as good an insulator as the low-density building envelope materials described earlier in this chapter. The lowest value we found was 0.139 W/m·K on the website[217] of a Taiwanese exporter of a product called Trilite RMS Board® having a density of 1100 ± 100 kg/m^3. Most MgO/Cl boards are somewhat less dense and would be expected to have lower thermal conductivities. However Magnesiacore lists[226] a significantly *higher* value of 0.216 W/m·K ("like a softwood") for their product, which has a density of 980 kg/m^3. Moreover, Strong-Enviro Board® is paradoxically rated at 0.24 W/m·K for both their denser 10 mm series (1000 kg/m^3) and their lighter-weight 18 mm series (850 kg/m^3), suggesting that density and the relative amount of the "popcorn rock" filler is not a factor. However note that magnesium oxychloride flooring, which is much denser (1500-2100 kg/m^3) than our composite sheeting made from the same magnesia-based cement chemistry, does apparently have a

[214] See http://www.magnesiacore.com/index.html.
[215] DragonBoard® product brochure dated March 15, 2005, no longer available online.
[216] See http://www.strongenviroboard.com/test.htm.
[217] See http://www.triliteboard.com/rmsboards.asp.

dramatically higher thermal conductivity, with a value of less than 0.7 W/m·K being reported in a review article.[195]

Electrical Conductivity. Some companies simply describe the board as "electrically non-conductive." *[We intend to research this further for more specific information in the published edition. –Ed.]*

Acoustical Absorption. Some MgO boards, notably those with a low-density, expanded rock core, are reasonably good sound absorbers, though the specifications we have found to date[217,218] are based on installation with a layer of rockwool, which we do not recommend. *[We intend to provide some information on this in the published edition. –Ed.]*

RF Attenuation. Texas consultant Jim Beal (www.emfinterface.com) took a radio frequency (RF) reading inside a square box built with ½-inch DragonBoard® sheeting and observed an overall 70% attenuation compared to "normal" readings.[219]

Breathability

To emphasize the importance of physical properties related to *breathability*, we devote this separate subsection to their consideration.

The MgO/Cl sheeting industry by and large says little and, if our inquiries are any indication, apparently knows little about these properties. Fortunately, however, based on George's experience in the field and our own limited investigations, MgO/Cl sheeting has excellent properties for making a thin-walled breathable building envelope. Here we will summarize what we have learned about the water vapor permeance, hygroscopic capacity, and capillary absorption/desorption of these materials

Water Vapor Permeance. We are unaware of a single MgO/Cl board manufacturer that has a vapor permeance specification for their product and we do not expect this to change soon. (See section 6.3 for a discussion of the fundamentals of diffusion, vapor permeability and permeance.) However, at least one of the companies, MagnesiaCore Inc., does point out on their website[220] that their product is highly vapor permeable:

> Magnesiacore is a breathable material being 26% air by volume[221] and microscopically of sponge-like consistency. This can be examined by pressing the lips against a piece of magnesiacore blowing air through it with pressure. It can also be verified by placing a piece of the material in a bucket of water and watching it float and then see it slowly sink as it becomes waterlogged. (Magnesiacore will dry out unharmed after getting waterlogged.)

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[218] See http://www.strongenviroboard.com/sound.htm.
[219] Jim Beal, personal communication with George Swanson.
[220] See http://www.magnesiacore.com/BreatheCoat.html.
[221] This value, according to Magnesiacore's Tony Carosi, was determined by measuring the weight fraction of water gained during immersion of the board.

These important natural properties not only make magnesiacore excellent at holding most all types of coatings, paints, fillers and adhesives but in fact allows for constructing walls and roofs that breathe rather than trap moisture. This helps prevent stale and unhealthy air, moulds and other unnatural environments from building up inside buildings and cavity of walls which tends to be the case when building with plastics and metallic sheet materials.

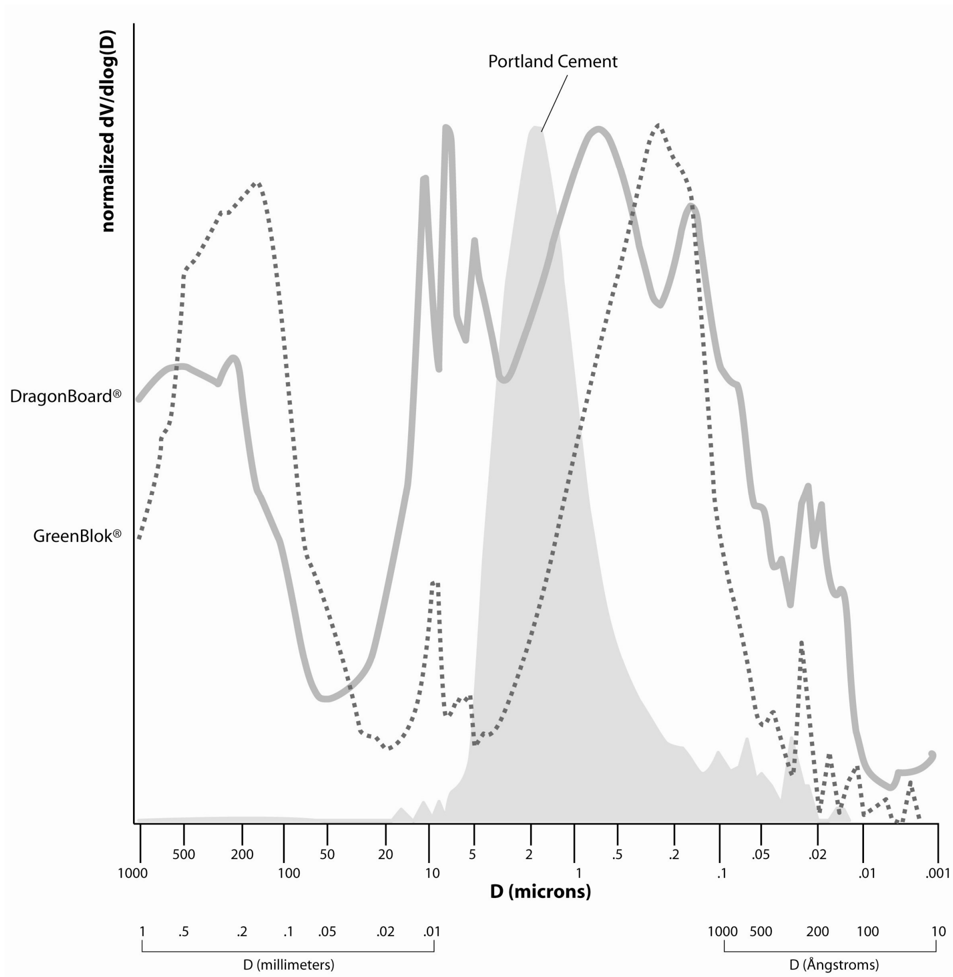

Figure 27. Pore size distribution, dV/log(D) versus D (where V=volume and D=-diameter), for magnesium oxychloride-based materials, DragonBoard® (grey solid line) and GreenBlok® (black dotted line), as compared to cured Portland cement without aggregate (grey shaded area). Measurements were performed by the Quantachrome Corporation using a mercury porosimeter.

In the last subsection we indicated that our results from mercury intrusion studies confirm the high level (50%) of total open porosity of DragonBoard®. Figure 27 above shows the actual distribution of pore sizes, revealing a predominance of pores within the microstructure that are sufficiently large in diameter (i.e., greater than 0.05 microns) to allow rapid diffusion of water vapor molecules through the material. From these data one should expect to measure high vapor permeance values for MgO/Cl sheeting.

Indeed Magnesiacore Inc. does provide us with a *range* of vapor permeance rates for their product, but only that which has been treated with their "partner product" BreatheCoat, an acrylic waterproofer that they say is breathable. Their webpage cited just above goes on to say that "BreatheCoat maintains an Air and Vapour Transmission Rate of between 5 to 15 perms."[220] That is, even with an acrylic coating, which we do *not* recommend because it reduces vapor permeability considerably more than does an equally effective and more durable mineral stucco paint (see sections 9.7 and 10.3), Magnesiacore's MgO/Cl sheeting is classified (presumably depending on its thickness, spanning the available range of ¼ to ½ inch) as either "semi-permeable" or "permeable" according to the convention proposed by building scientist Joe Lstiburek which is described in section 6.3. From Table 1 of vapor permeance values for a sampling of building materials in that section, we see that the acrylic-coated Magnesiacore® is at least as permeable as ⅜-inch plywood (2 to 9 perms), but less so than building paper (30 perms).

We encourage the MgO/Cl sheeting industry to test and provide water vapor permeance ratings of their product as sold, without any coatings or with silicate paint. These data will demonstrate that when using MgO/Cl boards, any trapped moisture within a wall cavity will be able to dry to the outside, and that no vapor retarder is required under any circumstance.

Hygroscopic Capacity. Chapter 6 (section 6.4) taught the value of hygroscopic materials for exchanging moisture in the gas phase and buffering the relative humidity within a building envelope, thereby preventing potentially harmful episodes of high moisture content within the wall cavities. We have not heard or seen anyone else mention this property in the case of MgO/Cl sheeting, but we think this might be an important benefit.

George recently observed the following, indicative of some degree of hygroscopicity for MgOCl board. A board having a weight specification of 68 pounds for 40 or 50% relative humidity (corresponding to the typical winter climate in his hometown of Austin) weighed 72 pounds during the muggy, 80 or 90% relative humidity weather of summer. This corresponds to a roughly six percent increase in weight, which represents a relatively good capacity for moisture adsorption. (By comparison, in the table in section 6.4, a hygroscopic material such as Durisol® low-density fiber-cement adsorbs an additional eight weight percent when the humidity is increased from 50 to 85% RH.)

There appear to be relatively few published reports of the moisture content of MgO/Cl sheeting, but we have found values for three different products on the market, rated respectively at 10%,[226] 8 ± 2%, and 9 ± 5%.[222] The latter values, reported for Strong Enviro Board® and Trilite RMS Board®, respectively, are the only *apparent* acknowledgement we've seen of the variable nature this measurement, although they make no mention of the probable source of the variability (humidity dependence). Depending on the shape of the water vapor adsorption isotherm, it is quite plausible that the Trilite RMS data, with its larger reported range, are quantitatively consistent with George's observations. At any

[222] See http://www.triliteboard.com/rmsboards.asp. The company also reports a very small "moisture elongation rate" of <0.9%.

rate, it appears that the equilibrium moisture capacity of MgO/Cl sheeting is large and variable,[223] which is good news for those interested in using this material to construct breathable, relatively thin-skinned building envelopes.

In an October 2007 phone conversation with the editor, chemist Mark Shand, resident expert at a major magnesium chemicals supplier and author of a recent book covering all practical aspects of magnesium chemistry,[224] confirmed that magnesium oxychloride is hygroscopic. Moreover Shand indicated that he expected the equilibration of this material with water would take place rapidly, making it useful for short-term humidity buffering.

Capillarity. All suppliers of MgO/Cl sheeting will tell you that if their boards are immersed in water and then removed, they will lose whatever water they have slowly absorbed[225] and readily dry out in air. At least two companies list the saturation absorption capacity of their sheeting. For example, Magnesiacore Inc. lists[226] a value of 26 % for their board, and Triple Lite Inc. reports[227] a value of 32% for Trilite RMS board. (We presume the units of these capillary absorption data are *weight* percent.)

The observation that the boards rapidly dry out after they are no longer submerged is all one really needs to know about capillarity. However, as indicated we did arrange for some of our own tests of a sample of DragonBoard® and got results back that help to explain *why* this is the case. As discussed and shown above, the size distribution of the internal porosity within the microstructure of DragonBoard® is plotted in Figure 27. Unlike the passage of water vapor described earlier in this subsection, capillary absorption or desorption of liquid water requires pores significantly larger than ten microns, the minimum size of a droplet, so we direct your attention to the left-hand side of the plot, which by convention displays the larger diameters at that end of the logarithmic x-axis.

It should be readily apparent in Figure 27 that in DragonBoard® there is a big population of very large pores having diameters greater than 100 microns—this is consistent with the sponge-like behavior of MgO/Cl sheeting, which can be accurately described as a very capillary-open material. (Recall from the discussion of section 6.5 that capillary action takes place within pore openings having diameters of tens of microns to millimeters.)

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[223] According to MagBoard's Gordie Ritchie (personal communication with Wayne Federer, November 5, 2007), variability arises from differences in the degree of completion of the reaction forming the magnesium oxychloride cement and the post-formation curing process in a controlled atmosphere.

[224] Mark A. Shand, *The Chemistry and Technology of Magnesia*, John Wiley & Sons, Inc., Hoboken, New Jersey (2006).

[225] Some manufacturers report saturation liquid absorption capacities for their products. For example, Magnesiacore Inc. lists a value of 26 % (http://www.magnesiacore.com /tests.html) for their board, and Triple Lite Inc. reports a value of 32% for Trilite RMS board (http://www.triliteboard.com/rmsboards.asp). We presume these values are in units of weight percent.

[226] See http://www.magnesiacore.com/tests.html.

[227] See http://www.triliteboard.com/rmsboards.asp.

It is also evident from Figure 27 that there are not only very large pores present, there are substantial numbers of what we will call "superpores" that are significantly larger than the experimental cutoff diameter of one millimeter. Just how much larger we don't know, but it is possible that some of these are large enough to form a capillary break, facilitating drainage of liquid water from the material and speeding the drying process.

Durability

MgO/Cl sheeting excels in its resistance to extreme environmental conditions, whether it be water immersion, freeze-thaw cycling, mold or fire.

Water Resistance. As indicated above, MgO/Cl boards are highly resistant to damage from immersion in water or freeze-thaw cycling. DragonBoard's website goes so far as to state that "DRAGONBOARD is completely waterproof. It will not disintegrate when immersed in water or exposed to freeze/thaw cycles for prolonged periods of time."[228] MagBoard reports[229] that their material "has been subjected to a controlled immersion test where samples … were placed in closed container of water and exposed to freeze and thaw cycles for a period of 36 months. At the completion of the test, there was no appreciable change in the physical properties of MagBoard." We haven't seen any more scientifically-based, objective test data to confirm these claims but George safely stored stacks of these sheets (both DragonBoard® and Strong-Enviro Board®) on his job sites in Austin, Texas, where builders had to contend with months of continuous rain in the spring and summer of 2007. When his crew needed a sheet, they picked one up from the stack, washed off the mud, took it inside and let it dry for one to four hours, and it was ready to go. One sheet was even accidentally buried for four months and appeared none the worse for it. You could never do this with wood-based plywood or OSB. Nevertheless, as detailed below and in sections 9.7 and 10.3, when the MgO/Cl sheets are used for exterior applications, George always recommends applying a breathable but highly waterproof overlayer.

Paul Danneman, Vice President of Sales for the S.E.B. Beta Building Materials Company in Houston, manufacturers of Strong-Enviro Board®, told us that when their factory in Shanghai was built in 1997, they covered the entire outside of the building envelope with their own product, totally unprotected from the elements (no finish or cladding of any kind). George confirms that the MgO/Cl sheeting is still in excellent condition after ten years. Paul also explained that engineers of large public works projects in China have been impressed with their sheeting's water resistance, particularly after it was installed in May 2007 onto the walls of a subway tunnel that were seeping water and it totally stopped the water intrusion.

As indicated earlier, the structural MgO/Cl sheeting products are all made of magnesium oxychloride (MOC), which is formed by the reaction of magnesium oxide and magnesium chloride raw materials. Therefore none of the sheeting products are phosphate-based (except for possible additives or surface treatments—see below) as are several of the alternative cements mentioned in

[228] See http://www.dragonboard.com/product-literature.php.
[229] See http://www.mag-board.com/properties.html.

section 8.9 and the exterior stucco products described in chapter 9. Phosphate-based magnesium is known as "liquid rock" and is extremely hard yet breathable. Magnesium phosphate is also waterproof, but that is not generally the case for magnesium oxychloride.

George explains that magnesium phosphate powder, such as made by Grancrete, Bindan and CeraTech, is waterproof when used as exterior stucco. The various MgO/Cl boards, on the other hand, are all made with magnesium oxychloride, which normally is *not* waterproof. The engineers of these boards have, however, modified the manufacturing process to produce a waterproof product. A recent book covering all practical aspects of magnesium chemistry by Mark Shand of Premier Chemicals, LLC, a major supplier of magnesium-containing raw materials, gives us some clues regarding the probable nature of this process:[230]

> Improvement of the water resistance of MOC cement by admixtures such as $ZnHPO_4 \cdot H_2O$ and $AlH_3(PO_4)_2 \cdot 3H_2O$ (Matkovic et al., 1976) as well as calcium phosphates (Matkovic, 1981, FHA Report) and other phosphate compounds has been documented (Deng, 2003). It has also been reported that the addition of silicates, such as serpentine and diopside, can also improve the water resistance of MOC cement (Vereshchagin et al., 1997).

Shand told the editor in an October 2007 phone conversation that addition of as little as a few percent of phosphate might suffice to protect the magnesium oxychloride (MOC) cement from leaching of the more soluble magnesium chloride phase. In June 2007 a report from the Central Road Research Institute of New Delhi, India demonstrated that incorporation of magnesium sulfate can actually stabilize MOC cement sufficiently well to be of possible interest for outdoor use.[231] (Also we should note that it is also known that over a longer period of time, atmospheric carbon dioxide will react with magnesium oxychloride to form a surface layer of magnesium chlorocarbonate, $Mg(OH)_2 \cdot 2MgCO_3 \cdot MgCl_2 \cdot 6H_2O$, which slows down but does not stop the dissolution of magnesium chloride.[230])

Finally, let us take note of three factors:

1. the well-known water instability of magnesium oxychloride, the primary chemical phase in MgO/Cl sheeting materials;
2. the proprietary status of the process that apparently overcomes this historical limitation of MOC cement technology; and
3. the potential for "bad" product to be imported from "fly-by-night" companies or those not having access to the legitimate secrets of the trade.

In light of these considerations, the success of the MgO/Cl sheeting industry in North America may ultimately depend on the development and widespread application of standardized testing to assure water resistance of the product, particularly for exterior use. According to Tim Faust of MagBoard, there are two

[230] Reference 224, p. 234.
[231] A. K. Misra and Renu Mathur, Bull. Mater. Sci., 30(3), June 2007, pp. 239-246.

ways to assure that this will happen. One is the development of standards by the International Code Council (ICC), for which a Chinese Ph.D. chemist is currently working on a water resistance test protocol as we write this. Regular testing will assure quality for those companies seeking ICC recognition of their product. Second, Faust plans to start a trade association that will, among other activities, police the MgO/Cl sheeting industry, testing and exposing any unsatisfactory products from suppliers that do not choose to seek ICC recognition.

Alkaline pH and Resistance to Mold, Insects and Microorganisms. By virtue of their alkaline pH, MgO/Cl boards do not support fungal growth and they are also resistant to termites, carpenter ants and bacteria. The pH is often in the neighborhood of 9.7 but may be as high as 11—lower than that of Hardiboard® or similar products made with Portland cement, which has an even more alkaline pH (greater than 11), but nevertheless a hostile environment for microorganisms. Indeed, magnesium oxychloride-based flooring is widely used in hospitals.

Fire Resistance. MgO/Cl boards have a two- to three-hour fire rating, depending upon the thickness. They are typically rated for 3-4 hours in single-layer 7/16 inch assemblies. They are completely nontoxic when used as intended and produce no toxic gases if they burn. They also maintain their structural integrity in a fire, not crumbling to powder as do some cement- and gypsum-based sheathing products available on the market today. This is a significant advantage.

Availability

MgO/Cl boards can be purchased through George Swanson at www.geoswan.com or www.substanceproducts.com, as well as directly through the manufacturers. The MgO companies all sell the sheets directly to the public, but George is an official representative for DragonBoard® and Strong-Enviro board® and sells the boards at the same price as the companies do. He and his colleagues have experience in installation and the use of these products. If you only need brief orientation to installing and finishing the seams on the board, call Casey Miller at Substance Distributing Co. (512-385-4326), and this information is provided to you when you order the board.

If you need a more extensive consultation then contact George directly (512-653-8624). George is able to do extensive finishing consulting, along with full house consulting, on a separate consulting contract. It is usually best for serious Baubiologie® clients to contact George first.

Integrated Systems

Lastly, there are also some businesses that install (sometimes with modifications) MgO/Cl sheeting as part of overall systems. *[We will describe these systems in the published edition. −Ed.]*

The use of waterproof yet breathable mineral stucco finishes, which is equally applicable to either thermally massive or lightweight (thin-wall) construction, is described in section 9.7. When you read section 10.3 you will learn hands-on techniques for using MgO/Cl sheeting on the construction site.

However first we end this chapter by examining some additional breathable materials technologies that we hope will become available one day in North America.

8.12 European Options

Up to this point the focus of this chapter has been on building envelope materials currently available to North American builders. Many of these preferred materials were developed abroad and only became available to us more recently. Some are still not manufactured in America but arrangements have been made for import.

Additional breathable envelope technologies are widely used in continental Europe but not currently available for import. The good news is that these represent opportunities for further advancement of the art of healthy building. In this section we shall briefly describe four European product lines, with the hopes that entrepreneurs will bring them to the North American market. We note that all of the products we highlight in this section have been imported to the United Kingdom within the last ten years or so, helping to break any language barrier that may exist.

By visiting the following websites of green building supply firms based in England, the reader can learn much about these and other European products:

Natural Building Technologies Ltd.	www.natural-building.co.uk
Construction Resources	www.constructionresources.com
Sustainable Building Solutions Ltd.[232]	www.sustainablebuildingsupplies.co.uk

Another useful English-language source of information is "the UK construction industry's definitive guide to 'green' building design, products, specification and construction":

GreenSpec	www.greenspec.co.uk

"Wood Wool" Panel

In section 6.6 we documented the virtues of external thermal insulation, nicknamed "out"sulation, to keep in the heat stored by a building envelope's thermal mass. Europeans widely recognize wood wool, usually in panels several inches thick, as an economical and sustainable way to "out"sulate their new or existing structures. Judging by our online searches this appears to a very common approach towards achieving energy efficiency and thermal comfort.[233]

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[232] Sustainable Building Solutions Ltd. is a regional agent of Natural Building Technologies Ltd. (NBT). We list them here only because their website provides a few useful comments not on the parent company's site.

[233] Aside from wood wool, **a**nother common form of external insulation in Europe is rockwool (also known as stone wool, mineral wool, granite wool or slag wool), in the form or rigid or semi-rigid slabs. Although there are still differing viewpoints among specialists regarding its safety, rockwool has been embraced by the Scandinavian green building industry and associated government agencies regulating their "passive house" market. Indeed the rockwool industry has in the last ten years made the fibers more

Wood wool panel, also known as insulation board, softboard, wood fiber insulation, or the German "Holzwolleplatte", is a mature product that has been around in parts of Europe for generations. (Gutex, a German company, touts their more than 70 years as a family-owned and operated business making this product;[234] we have reason to believe that the product has been around even longer.) In addition to "out"sulation, wood wool can serve a myriad of functions, from interior insulation in walls, roofs, and ceilings to underlayment for flooring. It is usually available as rigid boards that may be interlocking (tongue and groove) to eliminate thermal bridging. More recently flexible products have been introduced.

In a typical manufacturing process, spruce or fir chips are shredded, pulped and mixed with water containing nontoxic additives to render the product water-resistant and promote adhesion. The wood fibers are bound together by heating the pulp, which activates the lignin component. The pulp is then pressed into boards, dried, and cut to size. Alternatively, some products are made by a "dry" process utilizing a polyurethane binder resin.

Commonly available thicknesses of wood wool panel range from 20 to 120 mm (0.8 to 4.8 inches), suitable for different applications. These insulation boards have excellent thermal properties, comparable in fact to fiberglass batts. For example a 100 mm (4 inch) thick panel rates at R-14. (We have converted this to the non-SI units of °F·h/Btu used in the United States.) Unlike fiberglass, this material adds thermal mass to lightweight building envelopes.

Wood wool panels are easily cut and fastened and can be installed over timber or metal studs, masonry, or any of the breathable envelope systems discussed in this chapter. The sheets are an excellent base for natural stucco which can be applied directly over them.

Additionally, wood wool is vapor permeable and hygroscopic, it offers excellent acoustic insulation over a wide range of frequencies, and it has high compressive strength suitable for many load-bearing applications. The material is surprisingly resistant to fire, as the initial char formation slows down the intrusion of the flames, rendering a wall more fire-resistant than conventional lightweight construction. But the addition to wood wool of minerals such as magnesite (magnesium carbonate) can substantially improve the fire resistance as well as other properties. A UK-based distributor of the product manufactured by an

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soluble, shortening lifetimes for ingested fibers in the lung from a typical half-life of 300 days down to 20 to 60 days. Animal studies have allegedly indicated most of these newer materials to be non-carcinogenic under all but very restricted conditions of exposure. Nevertheless the Institut fur Baubiologie und Oekologie in Neubeuern, Germany (IBN) has maintained (in a September 2002 update of their correspondence course) that we cannot know at what moment the ingested fibers become carcinogenic. IBN states that the increased bio-solubility of these fibers is a step in the right direction but that the situation does not merit a blanket all-clear signal. We join IBN in urging precaution and recommend against the adoption of rockwool except in situations where it is more-or-less hermetically sealed within building materials as, for example, it is after it has been placed inside a wall of low-density fiber-cement wall forms. (For discussion of the latter application, see section 8.6.)

[234] See http://www.gutex.de/en/faqen.htm.

Austrian firm, Heraklith GmbH, states that this technology has been proven for 80 years in international use in all climates.[235]

We believe that wood wool panel is sorely needed in the United States, where there are no readily available alternatives. In contrast, builders who are "out"sulating in North America are primarily using expanded polystyrene (Styrofoam®, etc.) and other foam products that do not breathe properly and whose properties pale by comparison.

Further information on wood wool is available in English on the previously cited websites of UK green construction materials suppliers, as well as on the following manufacturers' websites:

www.steico.com [Select language from the home page.]
www.gutex.de/en/index.html
www.homatherm.com/uk/

Additional companies of interest include Pavatex.

Lastly, the following page is on the website of an interesting Irish builder who has adopted continental European "out"sulative technologies.

www.viking-house.ie/softboard

Porous Honeycomb Brick

[At the time of this pre-publication draft release, this subsection has been researched but not written. –Ed.]

Expanded Clay Block

[At the time of this pre-publication draft release, this subsection has been researched but not written. –Ed.]

Clay Board

[At the time of this pre-publication draft release, this subsection has been researched but not written. –Ed.]

8.13 Choosing the Right Materials

[This section, which will include at least one table comparing the properties and relative merits of the different materials described in this chapter, needs to be written and is omitted in this draft release of the book. –Ed.]

[235] See http://www.skanda-uk.com/heraklithProducts.htm#HBM.

Chapter 9. How to Construct a Breathable, Thermally Massive Envelope

We have presented the virtues of breathable, thermally massive envelope materials in previous chapters 6-8, first from a fundamental standpoint and then by introducing the various materials and manufacturers. In this chapter we take you to the job site and discuss how these products are used by builders.

9.1 Use of Low-Density Fiber-Cement Wall Forms on the Job Site

Both Durisol® and Faswall® brand low-density cement bonded wall forms are dry-stacked without mortar or extensive bracing, although some builders choose to use mortar to ensure a more straight and true wall surface. The blocks have hollow cores which the builder fills with rebar and Portland cement. (Our preference is non-metallic rebar to reduce potential electric or magnetic field exposure.) The wood-fiber-cement jacket is not designed to bear weight. That function is provided by the concrete core and rebar assembly.

As insulating concrete forming systems, low-density cement-bonded wall forms are fully load-bearing up to dozens of stories high without the need for mortar. This distinguishes them from GreenBlok® and autoclaved aerated concrete (AAC) described in chapter 8, which come in solid blocks, require a thin-set mortar between blocks, and are not designed to bear the weight of more than a few stories of construction.

The Durisol and Faswall blocks each have their own unique tongue-and-groove configuration at the ends of adjoining blocks to eliminate air gaps and give added structural stability to the wall. ShelterWorks states that "The interlocking end design keeps the wall forms in place."[236]

Shims are used to align the Durisol and Faswall wall forms once the first row is carefully plumbed and aligned. These shims are inserted as needed into the exterior surface of the wall to help create a flush inner surface. Both manufacturers recommend setting the first course on a mortar bed, laying the forms carefully using chalk or a string for proper alignment. The first course is the most important.

The installation manual provided by Durisol calls for erecting the entire eight to twelve foot wall and then filling the forms with concrete in four-foot passes, and no more than four feet per hour, so as to avoid blowouts of the material.[237]

[236] See http://www.shelterworksonline.com/product.html.
[237] See http://www.durisolbuild.com/Webdocs/Tech%20Guide%20(Photos).pdf , pp. 31, 36.

ShelterWorks specifies in their installation manual[238] to conduct your pour after you have constructed the wall to a height of four to five feet.

Figure 28. Set the first course of Durisol® carefully. (Photo courtesy of Durisol Building Systems Inc.)

Figure 29. Concrete pour into Durisol® cores. (Photo courtesy of Durisol Building Systems Inc.)

[238] To get the latest version, call ShelterWorks Ltd. at 541-929-8010.

High-slump concrete can be used with cement-bonded wood fiber wall forms because of their unique "free-draining" design.[239] Durisol recommends using concrete with a 7- to 9-inch slump, providing a faster concrete pour and a stronger inner core. According to the company website, "When pouring a very wet concrete mix, the Durisol material immediately starts to drain the moisture so that it does not result in weaker concrete, while ensuring that there are no voids and making the pouring process easy."[240]

According to the ShelterWorks website,

> …Concrete cures faster and more evenly [than normally] as the hydration moisture can be released through the wall form.[241]

The Durisol Building Systems website goes on to state,

> The Durisol material is considerably stronger than other ICF materials. Even with high-slump concrete, Durisol Wall Forms never blow-out during concrete pouring (when following requirements in our technical guide). Additional bracing is only required when the Wall Form units have been cut or altered on-site.[242]

The wall should not be disturbed for twelve days and load bearing should be held off for 28 days, according to ShelterWorks.

Rebar is installed throughout a wall constructed with either the Durisol or Faswall wall forms, both vertically and horizontally. This creates a "post and beam" configuration, according to the ShelterWorks website,[236] for added strength. Again, for the electromagnetically sensitive, we recommend using fiberglass rebar, which is more expensive than steel rebar, but is also lighter and stronger with built-in corrosion resistance. Suppliers of VROD brand of Pultrall's composite fiber reinforced polymer (FRP) material include Concrete Protection Products (336-993-2461; www.fiberglassrebar.com), Trancels Construction Technologies (888-726-2357; www.trancels.com), and Building For Health Materials Center (800-292-4838; www.buildingforhealth.com).

Conduit containing electrical wiring, as well as plumbing, can be run through the hollow cores in these blocks prior to pouring concrete. Wiring can also be routed into the inner surface of the block with simple hand tools. Coordination needs to occur between the electrical, plumbing and general contractors so that wiring and plumbing can be laid as the cores are filled with concrete.[243]

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239 See http://www.durisolbuild.com/Const%20Overview.shtml.
240 See http://www.durisolbuild.com/F%20Compare.shtml.
241 See http://www.shelterworksonline.com/product.html.
242 See http://www.durisolbuild.com/cons_zero.shtml.
243 Protocols on how to install wiring in a new or remodeled home that protect occupants from unhealthy exposure to electromagnetic fields is available from Oram Miller, BBEI (Environmental Design and Inspection Services, Minneapolis, Minnesota; 952-412-0781; www.createhealthyhomes.com) and Spark Burmaster, EE, BBEI (Environmental Options, Chaseburg, Wisconsin; 608-483-2604; eoptions@mwt.net) who wrote the protocol. Consultations are provided to clients nationwide by both Oram and Spark. Consultations are also provided by other Building Biologists through the Institute for

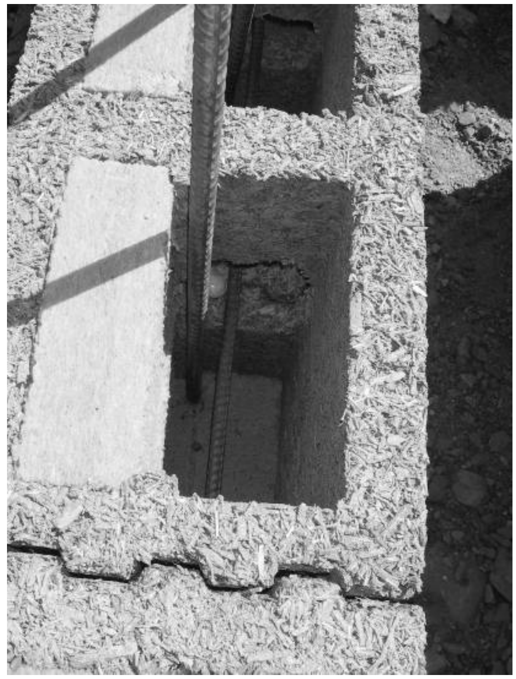

Figure 30. Placement of rebar in Faswall®. Note interlocking of adjacent forms. (Photo courtesy of ShelterWorks Ltd.)

Cement-bonded wood fiber wall forms can be formed into any shape at the factory. Durisol® wall forms are supplied in two- or three-foot lengths and stand one foot high. Faswall® wall forms are only two feet long and eight inches high. Special forms are used at corners and as lintels above windows and doors. According to the Durisol company website, "…bracing/scaffolding systems, rim joist / ledger connectors and drainage membranes" are all available."[244] According to the ShelterWorks website, their Faswall® wall form requires "Minimal bracing as compared to foam ICFs."

There is a certain degree of variation found by builders in the size of both company's wall forms. This is overcome at the job site by the use of shims, provided by the manufacturers. It is also imperative that the first course be straight and true. A scratch or brown coat of sand and cement smoothes all irregularities on the inner and outer surfaces and fills in voids. This provides a smooth, continuous surface for further coats of stucco and plaster. The use of shims results in a plumb wall inner surface. This allows easy mounting of wallboard directly to the interior surface, although our profession discourages the use of wallboard because you lose a certain degree of the outstanding breathability provided by a low-density wood-fiber wall. We instead recommend using clay or lime plaster as your interior finish because it is hygroscopic and can create the same look as wallboard, if a smooth surface is desired.

Bau-biologie® and Ecology, Clearwater, Florida, 727-461-4371, www.building biology.net (click on "Find an Expert"). Courses are available through the Institute for those interested in learning how to provide these protocols.
[244] See http://www.durisolbuild.com/products_access.shtml.

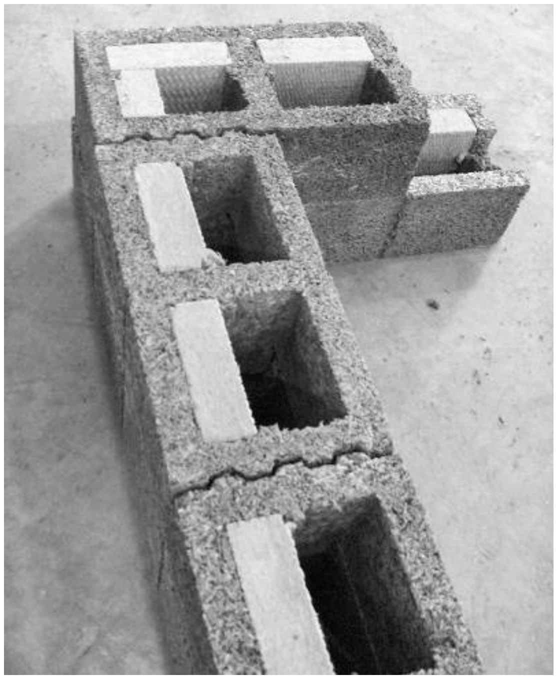

Figure 31. Interlocking at ends means minimal bracing before concrete infilling. (Photo courtesy of ShelterWorks Ltd.)

Figure 32. Positioning Faswall® wall forms. (Photo courtesy of ShelterWorks Ltd.)

ShelterWorks Ltd. has a unique system of providing an entire kit for its builder clients:

> ShelterWorks offers the Faswall product in Kit form. Each kit is comprised of the 4 wall form designs the builder needs to complete corners, openings, and lintels. This virtually eliminates waste on the job site as all wall forms are dimensionally interchangeable. No more searching for pallets of corner blocks or ½ blocks as all the tools needed are included in kit form on each delivered pallet. Wall Forms are 24"x12" wide x 8" high. ½ sized wall forms are 12"x12"x8" high.
>
> The "kits consist of (4) standard wall forms, (1) AM wall form and (2) ½ wall forms and covers 8 ft^2 of wall area.[236]

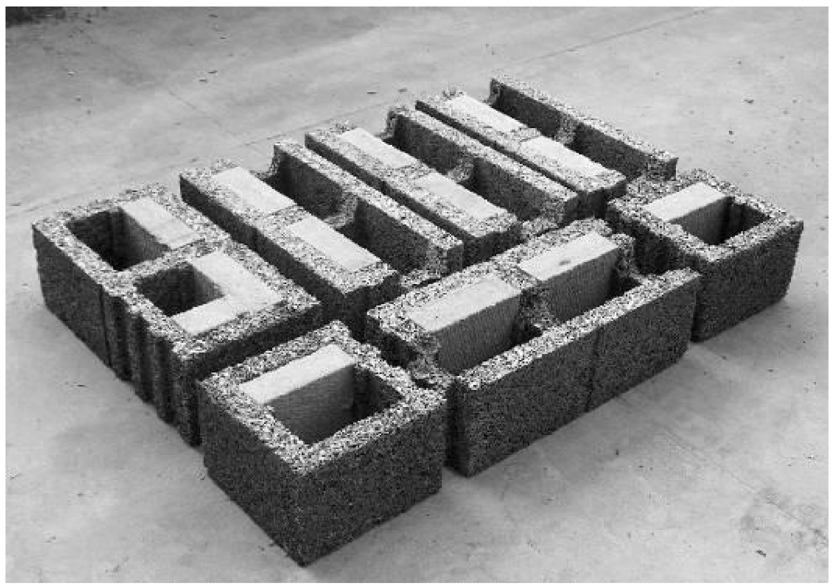

Figure 33. Components of the Faswall® kit available from ShelterWorks. (Photo courtesy of ShelterWorks Ltd.)

Cement-bonded wood fiber wall forms have full screw/fastener capacity, similar to soft pine. Builders use number six or eight deck screws with a large flange-to-shaft ratio to better hold in the material without spinouts. For heavier applications, such as stone cladding, use Tapcon® cement anchors, set right into the hollow core before the concrete pour. The Durisol and ShelterWorks builder's technical installation guides give extensive information on fastening cladding, wall board and masonry to their products.[245,238]

The roughness of the exterior of the fiber block provides excellent adhesion for stucco, meaning wire mesh and paper-backed products are generally not needed. George, however, had been adding fiber mesh in Austin only when he mixes custom blends of stucco on the job site for those clients who want all-natural ingredients (sand, lime, and white Portland cement). When that type of hand-

[245] See http://www.durisolbuild.com/Webdocs/Tech%20Guide%20(Photos).pdf.

mixed stucco is used, the mesh prevents cracking. Now George states he applies a fiberglass mesh on all low-density fiber-cement wall form projects.

When concrete and rebar are placed in the core of low density fiber-cement wall forms, approximately one third of the block forms a soft, breathable jacket around a dense concrete and rebar core, which provides thermal mass. (See sections 9.1 and 17.3 for discussion of rebar.)

As explained in chapters 6 and 8, ideally you want your wall to contain lightweight "out"sulation, with your insulation primarily positioned exterior to your thermal mass. The externally-positioned insulation can be cellulose, cotton, straw or rock wool inserts placed towards the outside of the hollow core. (The latter is used by Durisol as a pre-inserted insulation, while George Swanson often recommends an alternative infill – see section 9.3). Rockwool inserts complement the marked insulating capacity provided by the air pockets contained within the low-density cement-bonded wood fiber wall form jacket itself.

In northern climates the manufacturers recommend using a minimum ten-inch cement-bonded wood fiber form, while eight inches is recommended in southern climates. Durisol also makes twelve, and now a fourteen-inch block. ShelterWorks makes twelve-inch blocks for exterior envelope use. In the South you would use eight or ten-inch blocks for your envelope depending upon whether or not insulation against loss of air-conditioned indoor coolness is an issue– see below.

The Durisol Corporation recommends stucco as the best external finish. We agree. If Hardiboard is used he says to apply a parge coating to the wall as a weather and air barrier or rain screen under the siding, as discussed in section 7.6. Also see below for a specific protocol on how to apply siding to a Durisol wall.

Durisol® and Faswall® wall forms are easy to use on the job site and have good performance characteristics, which are described on the Durisol Building System Inc. and ShelterWorks websites. From the Durisol Building System website, under the heading "Easy to Use":[246]

> Builders choose Durisol because of the ease with which walls can be constructed. The Durisol material is light-weight, easily cut, nailed and screwed with simple carpentry tools.

From the Durisol Building System Inc. website, "Easy to Finish"[247]

> Interior and exterior finishes are applied directly to the Durisol material, eliminating subsequent steps in the construction process. Drywall can be attached anywhere on the Wall Form surface, while the open-textured nature of the hardened Durisol makes it an ideal substrate for plasters and stucco.

[246] See http://www.durisolbuild.com/cons_adetu.shtml.
[247] See http://www.durisolbuild.com/cons_advetf.shtml.

Figure 34. Faswall® is easily cut. (Photo courtesy of ShelterWorks Ltd.)

From the ShelterWorks website:

> Cuts with carpenter's tools. Takes screws and nails on all surfaces. No installation or searching for furring strips…
> Excellent substrate for plasters and stuccos; keys-in on the porous surfaces.[236]

Also from "How Does Durisol Compare to other ICF (Insulated Concrete Forming System) Products?"[248]

> Durisol Wall Forms are much stronger, and can withstand higher concrete pressures. …. Also, since the blocks are uniform, you can drywall or screw to any point on the finished surface, not just at the discrete plastic web locations [areas for fastening provided on polystyrene ICFs].

Durisol states that mortar should be placed between blocks in the first course to get the row perfectly level. Then use additional mortar later as needed to keep the rows level and the wall surface flush. As noted above, builders have sometimes used mortar for this purpose.

From the Durisol Building System Inc. website, "Winter Construction"[249]

> The insulating properties of Durisol Wall Forms allow winter construction without additional heating or insulation sources being required. Durisol wall systems have been constructed in temperature as low as 22 ˚F without any complication.

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[248] See http://www.durisolbuild.com/F%20Compare.shtml.
[249] See http://www.durisolbuild.com/cons_advWc.shtml.

When asked whether rockwool inserts were necessary in southern climates to keep coolness in, a Durisol representative said:

> We do recommend using the Wall Form with (rockwool) inserts. Actually, thermal mass effects are more pronounced in cooling climates. That is, the increased energy efficiency due to thermal mass is greater in climates that require air conditioning than heating climates. This is reflected in our thermal performance document if you compare heating loads vs. cooling loads, compared to conventional wood-frame construction. You can download this document from our website at www.durisolbuild.com. Click on "Downloads" and then "Tech Guide."
>
> Typically, basements in a hot climate should be the standard Wall Form (without inserts) and above grade should be R-14 (ten inch wall forms with inserts).

Durisol's protocol provides a choice between a ten- twelve-, or fourteen-inch block and in all cases the above grade blocks contain rockwool insulation. Durisol states that below grade the uninsulated blocks provide sufficient thermal insulation and therefore you do not need rockwool inserts except as an optional upgrade in Choice Two below.

9.2 Low-Density Fiber-Cement Wall System Protocol

Note: These protocols also appear in chapters 17 and 18.

The following protocol is provided by Durisol Building Systems. We recommend that you download and thoroughly review Durisol's Technical and Installation Guide.[245] *[In the final publication we intend to incorporate a similar protocol recommended by the K-X Faswall International Corporation. An updated Faswall Technical Manual is available by contacting ShelterWorks. –Ed.]*

Choice One:

1. Below grade use ten-inch R-8 uninsulated Durisol blocks (that is, un-insulated with rockwool insert).
2. Above grade use ten-inch R-14 rockwool-insulated Durisol blocks. Use eight-inch or ten-inch R-8 un-insulated Durisol blocks above grade in hot climates.

Choice Two (for added thermal performance):

1. Below grade use twelve-inch R-8 un-insulated or R-14 rockwool-insulated Durisol blocks.
2. Above grade use twelve-inch R-20 or fourteen-inch R-28 rockwool-insulated Durisol blocks.

Six- or eight-inch blocks (which only come un-insulated) can be used for non-load bearing applications such as interior partition walls.

The ten-inch R-8 un-insulated blocks suggested below grade as a foundation contain no rockwool and the entire 8½ inch hollow is filled with concrete and rebar. The ten-inch and twelve-inch R-14 blocks both contain 1½ inches of rockwool and 7 inches of concrete. The twelve-inch R-20 and fourteen-inch R-28 blocks each contain 3 inches of rockwool.

Below grade the ten-inch R-8 un-insulated block performs as well as 1½ inches of foam insulation, yet it is breathable. It also contains sufficient concrete and rebar within its core to be load bearing and provide structural stability for the entire house. Some clients choose to include the rockwool insert for additional insulation, though the company states it is not necessary in most applications.

Concrete block layers and masonry tradesmen can be easily shown how to construct low-density fiber-cement wall forms. Besides their comprehensive installation manuals, the manufacturers provide technical support to assist builders in all phases of installation.

The first protocol mentioned above performs well in Canada’s climate, providing energy efficiency and good thermal performance. It is the least expensive and most economical choice among the Durisol protocols. The ten-inch R-14 wall system will outperform an R-30 batt-insulated stick frame wall with 2x6 wood framing set 16 or 18 inches on center, according to Durisol.

The R-value increases with choice number two using the R-14 blocks below grade and the R-20 or R-28 wall forms above grade. This protocol can be chosen in cold climates if finances allow for it.

In both cases high quality doors and low-E windows plus adequate attic insulation need to be used to achieve the effective R-values listed.

With all its positive qualities, including fire and moisture resistance, the Building Biology® profession recognizes one downside to rockwool. According to Helmut Ziehe, founder of the International Institute of Bau-Biologie® and Ecology in Clearwater, Florida (727-461-4371; www.buildingbiology.net), rockwool is made from slag or tailings produced from very high temperatures in the iron and steel industry. As such it can contain toxic trace elements and is a recycled product. That is touted as a plus in the sustainable building movement, but building biologists and our clients take the opposite view because the process that produced the by-product was a toxic one. You also have the issue of the presence of small fibers in mineral wool (see below).

In subsequent conversations with Ziehe about this issue he has softened his position, stating that rockwool was an appropriate insulation material that should pose no significant health risk to building occupants. The rockwool insert is well contained within the wall form, and for that reason Ziehe subsequently gave his approval to its use. This is consistent with the position of the Institut fur Baubiologie und Oekologie Neubeuern (IBN) in Germany, which (as we noted in section 8.8, footnote 178) recommends against the adoption of rockwool except in situations where it is more-or-less hermetically sealed within building materials, as is the case with Durisol® and Faswall® wall forms. Care is recommended in their handling to minimize inhalation of fibers from the rock wool.

The next section provides alternatives to using rockwool inserts and concrete infill when constructing a wall out of low-density fiber-cement wall forms.

9.3 Alternative Protocol for Low-Density Fiber-Cement Wall Forms

To avoid the potential drawbacks of rockwool insulation, George avoids the issue altogether and provides an alternative protocol using cellulose, cotton or shredded straw as a replacement. While he uses the standard Durisol® and Faswall® wall forms containing concrete and rockwool inserts on many of his projects, George does offer this alternative protocol for do-it-yourselfers who want to avoid the use of rockwool and Portland cement in the cores of their forms. Concrete infill and rebar are replaced in the cavities of selected blocks with sand or tamped earth and rebar is placed only in selected locations. Bear in mind that this is not a protocol that Durisol Building Systems nor ShelterWorks endorses, but George has used it successfully with many of his clients over the years.

George feels there are more advantages to using his alternative protocol than just avoiding mineral wool. These include reduced use of Portland cement, which outgases, has deleterious health effects (as discussed in section 8.6) and requires large amounts of electricity to manufacture. High amounts of CO_2 are also emitted when it is made. The downside to George's alternative infill approach is that it is more labor-intensive and you do not have the official backing of the manufacturer.

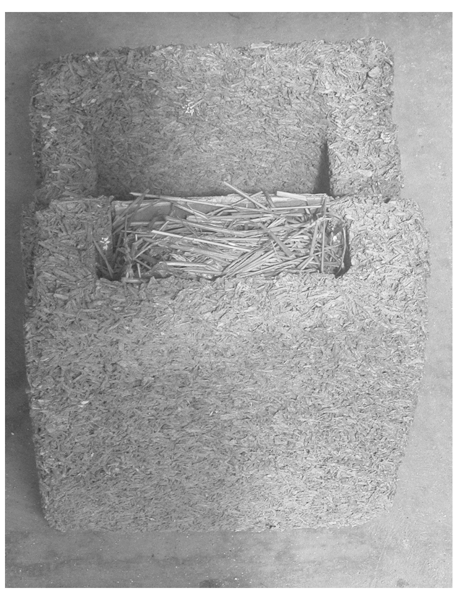

Figure 35. Alternative infill for low-density fiber-cement wall forms.

Alternative infills to concrete include lightly rammed earth, tamped earth, tamped sand or pea gravel placed in the inner half of each core of non-load bearing blocks. This provides substantial thermal mass. Selected cavities are filled with the required concrete and rebar, providing a "post and beam" structure to the building. See below. In all cases the outer half of each cavity is manually filled with cotton, cellulose or chopped straw as a replacement for mineral wool, creating an effective air-filled "out"sulation. The two materials (tamped earth or sand as thermal mass plus cotton, cellulose or straw as insulating infill) can be separated by manually inserting cardboard dividers.

For a one story building, George recommends placing concrete and rebar in the core of every fifth block cavity as well as in all corners, along the top of the wall (lintels) and above and around all doors and windows. This post-and-beam configuration is similar to that used in CMU or concrete masonry unit construction. Autoclaved aerated concrete (AAC) manufacturers likewise recommend using rebar in corners and around openings.

George's approach provides sufficient structural stability for single-story construction above grade while providing what he considers to be a healthier wall. Any dense infill can be used, as four out of five blocks do not have to bear weight. The concrete and rebar in every fifth block (plus corners, etc.) supports the load.

From a subtle energy standpoint (see section 6.10), rammed earth is the best infill material to augment thermal mass because humus (earth), crystals (sand) and rock all interact in a beneficial way, just as do the mineral and wood used in the low-density fiber-cement wall form jacket. George contends that rammed earth represents the most "living" material of all the alternatives that he recommends.

9.4 First-Hand Experiences of Builders Using Low-Density Fiber-Cement Wall Forms

In June 2004, during the writing of the initial draft of this manual, one of the authors contacted builders across the country about their experiences using the Durisol® wall form. The exchanges were initiated by a request from a client who was interested in using Durisol®, but had lingering questions. Each builder was asked a set of questions about six aspects of the construction process:

- the number of houses built with Durisol®
- their choice of finishes
- corner detailing of a Durisol® wall to a sheet rocked interior wall
- costs (compared to a stud frame house)
- straightness of Durisol® walls

- how each builder would affix wall board to Durisol® (if they chose to – many discouraged it!)

Bear in mind that up to the time of the conversations, all contractors had used wall form material purchased from the Durisol® Company prior to April 2004. It was then that Durisol® changed its production methods to create a straighter, truer block, and in general, builders are having less problem with variation. Yet their comments are still worth noting, because even today builders are saying that the blocks still have up to ½ inch of variability.

The following is a compilation of the builders' responses, starting with general comments:
Mark Morgan of Bear Paw Builders, Strum, Wisconsin (715-695-3265) says he was able to make both straw bale and Durisol® walls look identical to wallboard finish. As of 2004, Mark had completed three jobs, and he was building three more that summer. He uses gypsum-based plasters as his finish. Mark says the Durisol® material will naturally crack where it intersects with a sheet rocked interior wall due to different properties of expansion. He allows a confined straight crack to develop, then goes back and caulks, making it a clean joint.

Regarding costs, Mark says the finished product is not necessarily more expensive depending upon the experience of builder, especially if compared to an upgraded stud frame house. Mark points out that Durisol® is more expensive versus a concrete masonry wall. His cost is $20-22 per square foot for a walk-out basement.

To make the walls straight and plumb takes extra time when first learning how to use it, according to Mark. To affix wall-board to Durisol®, he uses coarse thread screws, such as those used to screw down Duraboard® to decks. He uses Centco's collated screwer, but says don't overtighten. Mark says there is no need to use furring strips.

Paul Conrad of Sun Valley, Idaho (208-726-3830), stated that he has a very good experience with Durisol®. He has a good relationship with Durisol and with architects who spec for it. He called it a "great product." Paul had built seven Durisol® houses as of 2004, all with three stories (a basement plus two stories). Paul uses cement stucco on the outside, plaster on inside. He says it is counter-productive to put drywall on Durisol® because it defeats the purpose. To avoid cracking at the Durisol®/sheet rocked inner wall interface, he uses lath or tape. He glues and screws the last stud right into the Durisol®. Paul's costs for Durisol® are 5-10% more, on average.

Paul says, unless you demand a smooth wall on the inside, you can get away with variations. "Out of whack" walls on the exterior are acceptable to him. He said the problem of an irregular surface is due to lack of detail during construction. He said you should think in terms of a true, plumb wall overall, not individual blocks. He says, you can't make every block perfect. Think in big terms. Get your corners "nailed" (straight).

Brennan Glantz, a physical engineer in State College, Pennsylvania (949-422-3818 cell, 877-684-8813) stated that he had no problems with Durisol® at all. He built the basement foundation of his own home with it. He found that it was an excellent use of materials versus 8-inch cast (poured) concrete, which, in his opinion, is an excessive use of concrete, as evaluated from the prospective of a physical engineer.

Brennan's cost for Durisol® was 30-40% more including concrete infill and steel. Brennan felt the increase in cost was justified because it is a better system. It cost him $2000 extra overall compared to concrete masonry, but he felt there would have been no increase in price compared to a poured concrete wall.

Brennan says his 60-foot by 9-foot basement wall "came out perfect." He says you could have put up wallboard right onto it. The masons did a good job of lining it up. The foundation was built by three Amish carpenters in one day. Brennan's carpenters then used drywall screws driven by a battery-powered drill. They used heavy duty coarse threads 2 inches long and experienced no pull-outs or stripping of the screws on the furring strips. He said you need a big enough screw to catch.

Naoto Inoue of Kennebunkport, Maine (207-985-0088 Ext.102, naoto@ gmail.com) stated that Durisol® is a "good product." He says there is no wicking of cold through the walls and that homes built with Durisol® heat well. He had built five homes with Durisol® for both foundations and above grade as of 2004. He says the homes can be built by carpenters. In his opinion, if plaster at the Durisol®/inner sheet rocked wall cracks, the builder did not use a fiberglass mesh.

Naoto's costs using Durisol® are generally 15% higher but he feels the homeowner will recoup that quickly in energy savings. He says the walls will behave like an R35-40 wall. The most important thing is to insulate the ceiling well, as much as R40-60. In general, the experience with homeowners he has built for in Maine has been that it costs 85% less to heat and cool with a Durisol® wall.

Regarding variability, Naoto said don't expect a flat-looking wall like a sheet rock wall. He said, "The variation is part of the charm." There can be up to 1/8 to 3/16 inch variation (again, using the older version of Durisol® before the April 2004 upgrade). Finally, Naoto was emphatic that you do not want to use drywall over Durisol® because it defeats the purpose of breathability. He said that if you use wallboard, then mold could grow on the paper backing.

A representative of Durisol Building Systems was also asked the same questions. He stated that Durisol® is equivalent in thermal performance to 1½-inch rigid foam and is more insulating than a poured concrete wall. He stated that Durisol® has been used in many tract houses in Ontario, for example, up to 1,000 per year. He said that hairline cracks at the interface with an interior wall can occur with natural plasters. The finish coat determines how it shows. He felt the solution to joining a Durisol® wall to an interior sheetrock wall is to use reinforcing mesh. He also recommended using paintable caulk as you do at the top and bottom of wallboard. He felt experienced plasterers will know this. (See the Durisol® website for technical guidelines on plaster and stucco application.[250])

[250] See http://www.durisolbuild.com/Webdocs/AUSTRIAN%20PLASTER%20STANDARD %20FOR%20DURISOL.pdf.

He stated that Durisol® is cost-competitive with poured concrete as a foundation, which is $4 per square foot unfinished. A ten-inch Durisol® block, on the other hand, is $6-7 per square foot (as of 2004) but you do not need to install additional insulation.

The representative explained that the manufacturing process was retooled in April 2004. The blocks are cast on pallets and are wet at first. For many years the bottom of each block was fixed on the pallet but the tops would split apart as it cured. Now the company uses a spacing mechanism to avoid splitting, yielding blocks that are more uniform. Finally, he recommends #6 or #8 deck screws to attach drywall. He said that only two out of eighty screws spun out in a recent application.

9.5 How to Use Breathable, Solid Blocks on the Job Site

GreenKrete®

Unlike Durisol® and Faswall® wall forms that contain cement and rebar within a hollow core, GreenKrete® blocks are solid and require the use of thin-set mortar. The blocks can be cored on site and reinforced with rebar for construction greater than three stories. They also have the potential of being used below grade as foundation walls, in seismic areas and high wind situations. GreenKrete® is an excellent foundation material as well as an envelope material above grade.

GreenKrete® blocks are lightweight, weighing approximately one half the weight of conventional concrete. Because they are insulating, the blocks require no additional insulation in cold climates. The material is fully breathable and able to handle any moisture intrusion without rot or mold growth.

Figure 36. GreenBlok® on the job site. (Photo courtesy of GreenKrete Building Systems.)

Because of their simple design, a home built with GreenKrete® requires fewer steps to construct. Walls are built in less time and with competitive costs compared to conventional stud frame houses. The blocks are about the same size as concrete masonry units (CMUs) and are erected in a similar way. They can be easily drilled, sawed, nailed, or screwed and routed into, just like wood, using carbide based tools.

Stucco and plaster is easily applied, as the blocks are a highly suitable substrate for these materials. We recommend natural, breathable mineral-based stuccos and clay or lime plaster finishes. See section 8.10 as well as section 9.7 below for details.

Figure 37. GreenBlok® is easy to cut. (Photo courtesy of GreenKrete Building Systems.)

Finally, GreenKrete is a pioneer in the use of radiant in-wall heat in winter and cool in summer. They embed hydronic tubing of cross-linked polyethylene in clay plaster on the interior side of their envelope blocks, providing a more evenly distributed heat than in-floor heating systems. See sections 14.6 and 14.8 for details.

Autoclaved Aerated Concrete (AAC)

Turning to another solid block, material, autoclaved aerated concrete, or AAC, is also a solid block requiring thin-set mortar. Most manufacturers provide a polymer-modified mortar designed for use with their product.

Figure 38. AAC on the job site. (Photo courtesy of SafeCrete.)

AAC is easy to work with and can be cut or drilled into. Since AAC is fully cured when it comes out of the kiln, there is no shrinkage or cracking as with concrete. There is also no warping, as with wood.

Figure 39. AAC is easy to cut. (Photo courtesy of SafeCrete.)

Rebar is required at corners, at the bond beam, and around openings in accordance with ICC Evaluation Report 1371. This and other installation details are provided by each manufacturer on their website, where you can locate technical guides as well as ASTM and other testing data.

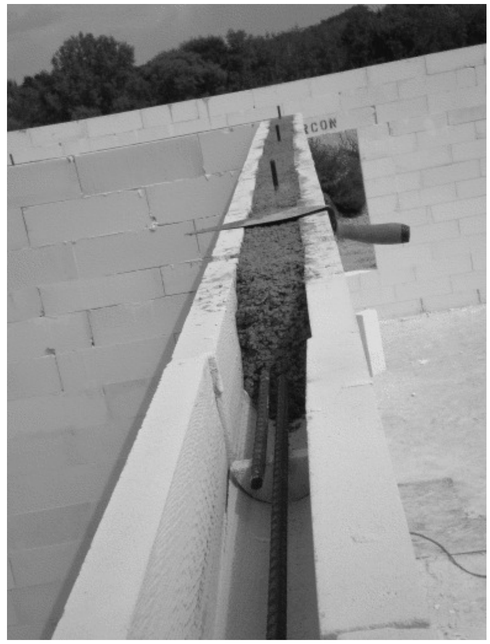

Figure 40. Rebar at the bond beam. (Photo courtesy of SafeCrete.)

Plumbing and electrical lines are installed in chases that are easily routed or sawn in the block. These are then patched with mortar or foam (nontoxic brands are available from green building retailers).

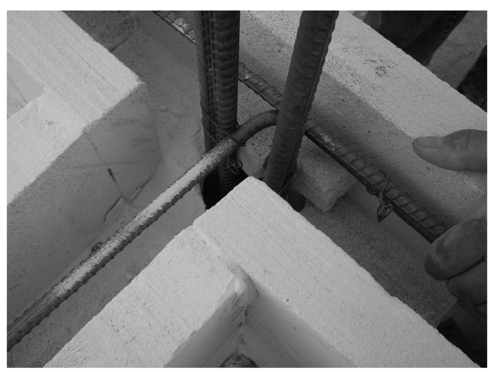

Figure 41. Rebar in AAC. (Photo courtesy of SafeCrete.)

Roof trusses are attached to AC, according to one manufacturer, E-Crete,[251] "using a top plate, anchor or ledgers consistent with other wall systems. Ledgers are attached to J-bolts that are installed at the side of the bond beam block with 4" concrete around the anchor bolt filled to the face of the wall."

For more information on installation, contact the specific manufacturer you plan to work with.

[251] See http://www.e-crete.com/faq/index.htm#6.

9.6 Window Detailing

It is important to mount windows no deeper than 1¾ inches from the outer surface of a Durisol® or Faswall® wall. This avoids water intrusion through the wall forms that encase the window, particularly if stucco is used as an exterior finish. Therefore it is advisable to avoid deeply recessed windows.

Secondly, it is recommended that metal window frames not be used as they may conduct moisture into the surrounding block.

In cases of water intrusion into a Durisol® wall, there is generally no concern for mold or internal damage because the wall form will easily transport water out, but the homeowner could experience water staining of interior walls.

Finally, the choice of window frames makes an important difference in thermal performance and cold air infusion in wintertime. Window frames made with more modern manufacturing techniques, including aluminum and vinyl, tend to substantially swell and shrink with variations in outside temperature, according to Ron Bessette of Fairfield, Iowa, and should therefore be avoided. Frames made with fiberglass, on the other hand, swell or shrink much less in response to outside temperature differences, reducing the cracking of your caulk.

We therefore recommend purchasing fiberglass windows of good quality whenever possible.

9.7 Breathable Finishing Treatments, Above Grade

Stucco

Thick-wall materials are excellent substrates for natural stucco and plaster finishes, providing a porous surface that readily accepts the scratch coat of both materials. This reduces labor costs, as the building process is simplified and several traditional construction steps are eliminated.

Contractors find that thick-wall materials are quite "thirsty" for the scratch coat of plaster and stucco, so budget for this. Durisol estimates this to be 25% more, while ShelterWorks says 20% more. Clay or lime plaster on the inside and a natural stucco, such as lime or magnesium phosphate, on the outside, are the ideal finishes, providing a fully breathable wall from inside to out. Cover external stucco with natural mineral silicate paints that provide a breathable, durable, penetrating waterproof top coat. These materials, when properly applied, last for decades with little maintenance, and they can be tinted in various colors. An indoor plaster finish can be just as smooth as wall board, providing a professional look to the interior décor. Plaster can also blend well with an intersecting gypboard-covered interior partition wall.

Figure 42. Stucco applied to Durisol® wall form. (Photo courtesy of Durisol Building Systems Inc.)

The primary benefits of plaster and stucco finishes include:

- Moisture within the wall dries quickly while rainwater is kept out
- Excess indoor air relative humidity is adsorbed by clay plaster without damage to the wall
- Minor amounts of indoor air can be exchanged with the outdoors for natural fresh air exchange without loss of thermal performance
- Beneficial, healthy negative ions are released
- Toxic vapors are not outgassed

Magnesium phosphate as an external stucco can be obtained from any of the following companies:

- Substance Distributing Co. in Austin, Texas (512-461-4126; www.substanceproducts.com)
- Bindan in Chicago (630-734-0277; www.bindancorp.com)
- Grancrete in North Carolina (919-597-2500; www.grancrete.net)
- CeraTech in Virginia (800-581-8397; www.ceratechinc.com)

In most cases MgO will represent about 30-40% of the entire mix, with masonry sand being the filler that you add. Be sure to check out the "reaction" time (initial set time) of each product. (George is available to consult on extending the reaction time.)

Magnesium phosphate stucco acts as an adherent and provides additional thermal insulation thereby creating more "out"sulation, discussed previously in section 6.6. Lime is also a useful stucco material. Both materials will not hold water when wet. Portland cement used as a stucco layer can also dry out in time if used as a breathable stucco material without the addition of acrylic, especially if it is applied as thin as possible.

George states that soon he will be offering premixed magnesium-based stuccos through Tom Lally of the Bindan Company (630-734-0277; www.bindancorp.com). These mixtures will only have a limited warrantee and are intended for use with the magnesium oxychloride (MgO/Cl) composite boards discussed in the preceding chapter and a magnesia-based joint compound. George is also hoping to soon offer a full seminar and certification program for use of magnesia-based stuccos applied over MgO/Cl boards. Warrantees will only be offered when these products are installed by persons certified by George's training program. Check his website for updates, www.geoswan.com.

George is now offering a full range of magnesium oxide stuccos, joint compounds, grout and mastics through Substance Distributing Co. of Austin (www.substanceproducts.com; 512-385-4326). George calls the stuccos "Magna-Blends, All Natural Mineral Based Powder Mixes." If you only need brief orientation to the use of magnesium stuccos, call Casey Miller at Substance Distributing Co.. If you need a more extensive consultation then contact George directly (512-653-8624). George is able to do extensive finishing consulting, along with full house consulting, on a separate consulting contract. It is usually best for serious Bau-biologie® clients to contact George first.

A representative of Durisol Building Systems recently weighed in on our use of magnesium phosphate-based stuccos and mineral paint finishes applied directly to his company's product, in a September 2007 email exchange with the authors:

> If your system as proposed by George Swanson works in similar climates on projects with similar design features (considerations of the home that either make it more or less prone to moisture problems), we would not object to the use of the system. That is not to say that we would endorse it and assume potential liability for the system. I don't think that is a fair responsibility to place on us.
>
> The other consideration is the potential for cracking/joint telegraphing. This was not addressed in your proposed system. *[George had been adding fiber mesh only when he mixed custom blends of stucco on the job site for those clients who wanted all-natural ingredients; he now recommends fiber mesh for all thick-envelope projects to avoid this problem. –Ed.]* We recommend stucco reinforced so as to minimize the potential for cracks as well as the dependency on installer workmanship. George's system will work and joints won't crack, but only if applied by knowledgeable installers with experience. Our experience has been:

> 1. Stucco with metal lath never cracks
> 2. Stucco without metal lath but with plastic coated glass fiber mesh seldom cracks (perhaps 10% of the time).
> 3. Stucco without continuous reinforcement cracks 50% of the time (when not applied … correctly with due consideration for weather, curing conditions, thickness of each coat, etc…).
>
> Again all of this is dependent on:
>
> 1. Where the project is
> 2. When the stucco is applied and how it is cured
> 3. Who applies the stucco and their experience
>
> As a manufacturer we can not provide unqualified recommendations other than the systems that we have outlined in our tech guide. It is our duty to provide the system that we know will work and is least dependent on the 3 items above.
>
> Please remember that we are the manufacturer of one component of the wall assembly, it should be the designer that approves the overall system. We are upfront that our system is porous and requires a weather barrier. We are also clear to explain that our system is more "forgiving" from a moisture storage perspective – it does not wick moisture and can store considerable moisture before water propagates through the entire wall thickness. It does not however stop moisture. As long as these characteristics of the Durisol material are taken into consideration along with the items above, the system should work. If there is a location on the wall where water/rain gets concentrated, you can have a problem without a moisture barrier directly against the Durisol.

Durisol Building Systems does indeed recommend a weather barrier under any stucco or siding over its wall forms. They make the important point that vapor barriers prevent moisture and condensation while air barriers prevent heat loss and maintain energy efficiency. This is a valuable distinction. In fact, one does not want to use a *vapor* barrier with thick materials, because they hinder the natural buffering and regulation of humidity made possible by the high permeance of thick wall materials. Durisol goes on to say most thermal performance and moisture problems are instead caused by air leakage and not vapor diffusion. An air barrier is therefore integral to the Durisol® wall system and can be placed either on the interior, exterior or within the wall itself. This can be accomplished by a number of means, including a continuous exterior parge base coat, continuous coatings of stucco (either synthetic or natural), exterior building wrap (which we do not recommend), or the use of the airtight drywall approach on the interior.[252] The air barriers we recommend, that is, a parging base coat of three parts sand to one part Portland cement and/or multiple layers of natural stucco, will be breathable to allow moisture vapor to escape.

[252] See reference 245, p. 45.

George's experience is that when thick wall materials are used in northern climates, you can provide weather protection with either natural stucco or, if you have attached cladding, by providing a simple lime, magnesium oxide or Thoroseal® parge coating on the exterior of the wall, beneath the cladding. ShelterWorks recommends using breathable felt paper under their Faswall block, which is code in many locations, although we believe the parging choices suggested above work as well or better and a variance can be applied for with the building inspector if necessary. The exterior weatherproofing system proposed here is an optional base coat of sand and cement (with or without Thoroseal if you are in a high rainfall climate), then magnesium phosphate stucco covered by silicate stucco paint. This combination is as or more waterproof than building paper, with a higher permeability for water vapor release from the interior of the wall. This ensures full breathability coupled with rainwater protection.

The Durisol® technical and installation guide has a table with specific recommendations for weatherproofing with each siding option.[253] Among the choices they recommend, if you use Hardiboard® or wood siding on the exterior, for example, we believe it is best to first apply a parge layer of sand and cement followed by Thoroseal®. Use a standard 3:1 ratio of sand to cement and provide strapping – see below for the protocol. The parge coatings smooth the surface, provide an air retarder under the siding, and protect the wall from weather while still allowing it to breathe. That way, when strong, wind-driven rain does penetrate cladding applied over a thick wall, the air gap allows the wall to dry out before mold can grow. When you use stucco as an exterior finish alone, no additional air barrier is needed because the stucco itself is an effective air barrier, unless you are in a climate with high moisture and wind-driven rain, in which case you would want to add a sand and cement and/or Thoroseal base coat. Likewise an air gap is not needed because the finish coats are water-resistant and the block is vapor permeable and able to handle the water exposure.

Plaster applied on the inside adds another breathable air retarder to the wall if Hardiboard® or wood siding is used externally rather than stucco, adding to your effective R-value.

It is important that you wait until the cement poured into the core of Durisol® forms has fully dried out and the base coat has been allowed to develop the inevitable hairline cracks before you apply subsequent coats. Also the surface must be prepared and all gaps filled in before applying your base coat. Loose fibers or woven reinforced mesh should be used. A separate set of guidelines for applying plaster and stucco is available from the Durisol website "Downloads" page. Click on the link for "Plaster and Stucco Guidelines for Durisol."[250] Faswall (541-521-0999; www.shelterworksonline.com) recommends in its technical manual that the concrete infill be allowed to set and cure, typically up to 5-10 days, before you apply stucco and plaster.

A representative of Durisol Building Systems advised several years ago, "With siding, I would recommend using Tyvek® house wrap and strapping." When asked what protocol he would recommend for homeowners who wish to avoid using house wrap, which our profession recommends against, he replied with the

[253] See reference 245, p. 46.

following alternative protocol, which allows you to nail siding into the parge layer:

1. Build the Durisol® wall.

2. Before pouring the concrete, place the strapping against the wall with screws protruding into empty cavity. This way, when the concrete is poured, it will embed the screws in concrete and the strapping then becomes securely fastened to the concrete core. Alternately, you can attach the strapping to the wall after the concrete is poured, using Tapcon® concrete anchors. Either way, it is recommended that the strapping is attached to the concrete core and not just Durisol® (low-density fiber-cement jacket).

3. Parge the wall, in between the lines of strapping. This will provide a very good air barrier.

4. Attach siding to the strapping.

Durisol also recommends Simpson® NSP 2 Nail Stop anchor plates[254] to attach siding. The attaching of siding, masonry and stone cladding is covered in detail in Durisol's Installer's Guide.[245]

Historically acrylic-based exterior stuccos have had generally unacceptable breathability characteristics and are generally not recommended by George because they disallow the wall from quickly drying when exposed to moisture. Recently many of these stuccos have been reformulated with much higher rated "perm" values. George feels these products are not needed and can be counterproductive. Plastic vapor barriers are also not needed inside or outside, as tests and field experience show that the block maintains superior thermal performance when stucco and plaster is instead used as a vapor or air retarder. As discussed in chapter 7, applying an older version of house wrap that had virtually no vapor permeance and breathability did not allow moisture that entered the wall to dry before mold could grow. The block must "breathe" while disallowing liquid water from entering. Although many building codes require a plastic air retarder at least on the inside, this practice, while not ideal, still allows drying to the outside, as long as natural stucco is used without exterior plastic house wrap. Newer changes in some building codes require at least "double D" felt building paper under stucco. Our position is that if your local building code requires this, choose a product that provides the maximum breathability to enable moisture within the wall to escape. Even DuPont's newer version of Tyvek® StuccoWrap®[255] has a perm rating of 50, which is far higher than it used to be, compared to a perm rating of only 10-30 for most building papers. DuPont also claims that its product does not absorb moisture from the scratch coat of stucco like building paper does, thereby disallowing the stucco from cracking and shifting during the critical early phase of curing and hardening. They say that otherwise, hairline cracks can develop, creating a gap between the stucco and its

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[254] See www.strongtie.com.
[255] See http://www2.dupont.com/Tyvek_Construction/en_US/products/residential/products/stuccowrap.html.

lath and weakening the stucco. Making the stucco stronger also ensures less chance of water penetration later.

The one disadvantage, however, that George points out regarding plastic house wrap is the likelihood that even newer versions may eventually lose their permeability with wear over the years. George has seen sections of house wrap become impermeable to the passage of water vapor after successive freeze/thaw cycles and the passage of time.

House wrap, building paper and synthetic base and top coats are therefore not our preferred waterproofing materials when they are not mandated, but when code leaves you no choice use the most breathable options you can. We would urge you to petition your local building inspector to accept the magnesia-based stucco and mineral paint combinations presented in this chapter as an acceptable alternative to building paper or house wrap.

Mineral Stucco Paints

Mineral stucco paints are relatively unknown in this country but have been used in Europe for years. They provide a remarkable ability to resist rainwater yet retain breathability over decades, if not centuries, of use. We first discuss the problems with currently used synthetic stuccos.

Some users of magnesium oxychloride low-tech composite ("MgO/Cl") sheets in China today have applied plastic-containing acrylic stucco to the exterior of buildings with unsatisfactory results. Builders in this country are having the same experience with the use of acrylic stucco in exterior walls. In the case of builders in China, George states they misunderstand how the board works stemming from a mistaken concern that it holds moisture. In fact the board does not hold moisture but rather transfers it out with no structural damage provided it is coated with a stucco that allows moisture to escape.

Newer acrylic stuccos have been redesigned with water vapor permeance ratings of up to nearly 40 perms (as permeable as building paper) for a nominal 1/16-inch fine-aggregate coating because manufacturers have responded to problems with the impenetrability of previous formulations. The problem is not solved, however, because George speculates that after twenty years of freeze/thaw cycles, the pore structure of the acrylic may still collapse, thereby eventually sealing up portions of the exterior finish. According to the Keim company, ultraviolet photo-degradation is another possible failure mechanism, despite attempts to stop this with uv-absorbing fillers. When synthetic stucco covering a conventional wood-frame wall loses its porosity, moisture is trapped and any loose fill or batt insulation loses its insulating value and develops mold. The MgO sheathing itself cannot rot nor mold from the presence of moisture, but problems do develop in the wall cavity. Moisture build up in the walls defeats the purpose of the MgO board which is always naturally breathable when not sealed with a plastic exterior finish. Otherwise the building envelope fails after some decades.

The solution is to choose natural mineral-based stuccos as your final coat on the exterior that will still breathe many decades from now. That is the guaranteed way to get the perfect surface on any substrate, and maximize the advantages of MgO boards. The best solution, according to George, is a bio-compatible mixture such as Keim® or similar natural stucco-paint compound. Keim® (http://www.keimfarben.de/en/) is a potassium silicate paint that has been used throughout Europe for over a century in the commercial paint industry as a premium coating. It was developed in Bavaria in 1878 by Adolf Wilhelm Keim. It is known in Germany as one of the "grobs," the term used for a material that is both stucco and paint. Keim® is available in the U.S. through Keim Mineral Coatings of America, Inc., Charlotte, North Carolina (866-906-5346; 704-588-4811; www.keim.com). It is also available through Keim Mineral Systems in Lewes, Deleware (302-684-3299; www.keimmineralsystems.com).

Keim® stucco-paint is designed to penetrate and chemically bond with the material to which it is applied. Traditional paints merely coat the surface. Keim®, on the other hand, utilizes potassium silicate as its binder, creating an extremely hard and durable bond. Traditional paints use organic petroleum binders to adhere by adhesive bonding, leading to failure over time. The durability and colorfastness of Keim® silicate paint is seen throughout Europe on buildings still in excellent condition that were painted one time over 125 years ago.[256]

Other manufacturers of mineral paint state that standard latex formulas fail because moisture gets trapped underneath an impenetrable layer that disallows evaporation. The moisture cannot dry, lifting the paint from the surface in blisters. As a result the paint peels prematurely. Aging also causes the latex resins to fail.

Potassium silicate paints, on the other hand, bond directly to the surface by penetrating deep into the microstructure of the substrate. Eco House Paint Company of New Brunswick, Canada calls this "petrification into a stone-like micro-crystalline coating, which repels liquid water, but allows water-vapours to pass through." These paints also do not degrade with age. As a result, they can not blister or peel.[257]

A typical layer of Keim® mineral paint is so extremely vapor permeable that it offers the same resistance to water diffusion as a thickness of air of at most 1 or 2 centimeters.[258] But at the same time it is 100% waterproof (capillary closed),

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[256] See http://www.keimfarben.de/en/.
[257] See http://www.eco-house.com/silicate_paints.htm.
[258] The vapor permeance in perms is extremely difficult to define for a penetrating coating such as mineral stucco paints, as the substrate chosen will make a big difference in the measurement. Values of 100 to 600 perms would be the result if one insisted on quoting such a specification. A more meaningful number is the German DIN standard for construction vapor diffusion resistance, Sd, used in continental Europe. An Sd value, measured for a standard substrate, corresponds to the thickness of air in meters offering the same resistance as the sample in question. Keim products have Sd values ranging from less than 0.01 up to 0.02 meters. Elsewhere we have seen values as low as 0.006 meters listed for silicate paints.

The Sd value is also equal to the thickness-independent μ value, briefly mentioned in a footnote in chapter 6 where we introduced the perm unit used in North America, multiplied times the sample thickness. Using a typical coating thickness of about 100 μm disallowing rainwater droplets from entering the envelope while allowing water vapor inside the wall to dry to the outside. This is analogous to the mechanism of the skin of a human being keeping water out but allowing sweat to exit and evaporate to the outside air.

George states that up to five layers of preparatory coating need to be used on existing surfaces before Keim® paint can be applied. This is because normal surfaces, such as steel or concrete, are not naturally breathable. The preparatory coatings are necessary to "teach the surface to breathe," according to George. Only then can the Keim Company issue its legendary extended 40-year warranty. Once the preparatory process is completed, Keim® paint has the capacity to "pull out" moisture, thereby curing the surface so it does not rot, blister, mold or discolor. The painted surface resembles velvet.

When Keim paint is applied to MgO/Cl board rather than concrete or steel, on the other hand, in most cases only one coat is necessary. This is possible because the board already has the capacity to breathe. No preparatory coats are needed. You create a mineral to mineral bond. In essence you enhance the waterproofing capacity of the external surface of Chinese-made oxychloride board without significantly decreasing its vapor permeability. George therefore recommends a single layer of MgO sheathing or layers of natural stucco and a single coating of natural stucco paint over all thermally massive, thick wall materials.

Furthermore, George recently sent samples of DragonBoard® MgO sheets to the Keim Company, where the technicians were very impressed. After preliminary testing Keim told him that MgO board is one of the few substrates a customer could apply their paint to in one layer and still receive their warranty, on a case-by-case basis.

Besides the Keim Company, three other manufacturers of natural mineral silicate stucco-paint mixtures sell to North American customers:

- Edison Coatings in Plainville, Connecticut (800-697-8055; www.edisoncoatings.com), makers of EverKote 300®.
- Silacote, with offices throughout the country (800-766-3157; www.silacote.com), makers of "fully tintable inorganic mineral silicate paint."
- Eco-House, Inc. of Fredericton, New Brunswick (877-326-4687; www.eco-house.com)

As an alternative to the prepared stucco mineral paints made by these four manufacturers, George Swanson creates his own mineral stucco mixes on job sites in Texas using a higher percentage of magnesium phosphate than the commercial manufacturers (see below). This provides a "rock hard" surface that is completely compatible with MgO/Cl board. The mixture replaces the standard stucco formula used by conventional builders, which normally includes a sheet of bitumen covered with two to three layers of cement stucco applied on a metal mesh. These layers are then typically applied over a paperless gypsum exterior

(micrometers), it is possible to convert these Sd values to perm rates using the formula given in that footnote.

sheathing panel. In George's experience, gypsum board will hold moisture and is now made with chemical fungicides to prevent mold. The installed cost of George's stucco mixes varies tremendously according to the labor market and the job site, to name just two factors.

The stucco cements mentioned in this manual, on the other hand, allow natural hydration because of the board's nearly completely natural moisture vapor permeability. If moisture enters these walls, it usually dries within two to three hours, even if water is sprayed on a wall under high pressure. Moisture can remain within a MgO/Cl board indefinitely with no damage when used for exterior sheathing provided it is manufactured according to the methods developed by the Chinese to ensure water tolerance – see Durability subsection of section 8.11. The board constantly transfers moisture outwards.

Furthermore, organic insulation, such as cotton batting, dries well within the time required for mold to grow. The board is completely mold-free under any and all conditions due to the natural antifungal properties of the mineral composition.

While a stucco paint exterior finish successfully inhibits wind-driven rain from entering, one can add a product known as Miracle Cover® (800-304-7325; www.miraclecoverinc.com), a penetrating but highly breathable, nontoxic, water-based silicone rubber sealer and waterproofer, to enhance the water resistance of the mineral stucco-paint mix. As a breathable waterproofer, outside rain beads up on its surface, but moisture vapor can exit from inside the wall cavity. Miracle Cover® comes with a 25-year warranty and is tolerated by chemically sensitive individuals.

One practical note: If Miracle Cover® is brushed on *after* stucco paint is applied, you will never be able to apply a new coat of stucco paint any time later if you want to change the color of your building. This is because Miracle Cover® repels any new paint. In fact, it is marketed as an anti-graffiti coating for public buildings and road signs.

If you mix Miracle Cover® right into your coat of stucco paint, on the other hand, you achieve water repellency while retaining the ability to apply a new color of stucco paint in the future. Be sure to check with the manufacturer's recommendations for the ratio of Miracle Cover® to add to your paint or stain.

During freeze-thaw cycles, a wall cavity takes on moisture by day, driven by the warmth of sunlight. You only have a window of a few hours when the wall must dry any accumulated moisture before it freezes again. Many conventional materials cannot dry within this time but drying does occur when using a MgO/Cl board and mineral stucco coating.

These coatings can be provided in one of two ways: either by using a pre-mixed mineral silicate paint/stucco or a magnesium phosphate-based stucco blend custom made on-site. These blends should be applied by certified installers trained by George Swanson, using his proprietary blends. These blends must be mixed properly under controlled conditions, because they set extremely rapidly. George is willing to train builders in the preparation and use of these blends on-site. As noted above he offers magnesium products, including "Magna-Blends," through Substance Distributing Co. in Austin, Texas (512-653-8624; www.substanceproducts.com). Contact George at 512-653-8624 or www.geoswan.com.

For interior applications, the same procedures used on conventional sheetrock can be used, with Murco® (800-446-7124; www.murcowall.com) as the recommended mud joint and texturing compound. Although Murco®'s most commonly used interior product is M-100, do check with the manufacturer for the best product for your specific application. The seams can also be beveled slightly or "capped" and the near white sheets (with small specs of wood chips in the DragonBoard® version) can be transparently stained and/or sealed with Miracle Cover®.

Cladding

On above-grade walls, cladding materials can also be used over thick walls, providing virtually the same benefits described for stucco. Our recommended choices include a wood fiber-cement product such as Hardiplank® or wood shakes such as cedar. When using these cladding materials, we recommend that you provide an air gap between the cladding and the block. A breathable air barrier must be applied to the wall form surface, such as the parge coatings described above. Cladding is fastened to furring strips that are first attached to the block using Tapcon® screws embedded all the way through to the hollow core before concrete is poured. Once concrete fills the cavity, the screws are anchored and even heavy stone cladding is safely secured. See above and below. When using solid blocks such as GreenBlok® or autoclaved aerated concrete (AAC), cement anchors can be embedded right into the block, which will hold cladding.

We do not recommend metal siding (aluminum or steel), or steel studs for that matter. The primary reason is that you do not want to inadvertently allow an electric charge to flow onto steel siding or studs anywhere in the building. Electric current unfortunately flows on the grounding systems of most homes in America, and since metal outlet and light fixture boxes are bonded to steel siding and metal studs, this causes electric current to flow where it does not belong, resulting in magnetic field exposure for occupants.

Interior Finishes

Regarding interior envelope finishes, clay or lime plasters are ideal choices. As explained in section 6.4, clay adsorbs up to roughly half its weight in excess moisture vapor from indoor air, further adding to a thick wall's capacity to naturally regulate indoor air humidity. Homeowners comment on how dry and comfortable their thick-wall home feels, even in humid climates such as Louisiana (see section 8.8).

Hairline cracks in the interior wall can sometimes occur with the use of natural plasters. All stuccos and plasters will crack. The finish coat determines how it shows and allowing the base coat to cure thoroughly. If the cracks follow the outline of the blocks, this is due to curing of the plaster and what elastomeric additives are present.

Most homeowners want natural cement or lime plaster, which will crack more than synthetic acrylic polymers. This depends upon the installer. If you add acrylic, which we do not recommend, it minimizes the need for strict curing conditions because the elastomers do not dry out as fast, which causes cracking. You therefore have a slower cure which minimizes cracking.

To avoid cracking with natural plasters, George recommends that you moisten the walls for several days by applying water while curing the plaster. On exterior walls, use a sprinkler which moistens the wall a couple of times a day for a few days. You can even let the base layer dry and crack. Then apply your finish layers.

Clay plaster also allows for the installation of an in-wall hydronic (water-based) heating and cooling system, in which hot or cool water is circulated through plastic micro-tubules embedded in the plaster. We discuss this in detail in chapter 14.

If plaster is not used on the interior, wallboard can be directly nailed to the inner surface of breathable envelope blocks. The downside is that you lose breathability and introduce some degree of toxicity from the paper used to line wallboard on the inside. Tape and caulk the wallboard using aquarium-grade, nontoxic caulk to provide a sufficient internal air barrier to maintain superior R-value. This constitutes the airtight drywall approach referenced above. Avoid foil-backed wallboard, as this does not breathe. Also be sure to use nontoxic joint compound, available from American Formulating and Manufacturing (619-239-0321; www.afmsafecoat.com). Murco 100 Joint Compound (817-626-1987; www.murcowall.com), made with nontoxic binders and fillers, can also be used. George recommends thinning it to create a great interior texture.

9.8 Breathable Waterproofing, Below Grade

External Waterproofing

Below grade we recommend applying a parge layer of a cement-based waterproofer such as Thoroseal®, made by BASF Chemical Company (952-496-6000; http://www.thoroproducts.com/products_waterproofing.htm). The Thoroseal® is brushed onto the exterior surface of any of the thick wall materials mentioned in this chapter, all of which make excellent foundations. Some builders report that low-density fiber-cement wall forms absorb the Thoroseal® “as if it wasn’t there.” George’s answer is to first apply, under the Thoroseal®, a standard scratch or “brown” coat of three parts sand to one part gray Portland cement as you would above grade, or to simply use a thicker, dryer coat of Thoroseal®.

We do not recommend asphalt, the traditionally used foundation waterproofer, because it is composed of a non-renewable resource (petroleum), it outgases a toxic vapor, and it has no significant elastomeric properties. This means that as the typical poured concrete or concrete masonry unit (CMU, or cinder block) foundation wall cracks, as it inevitably will, the asphalt cracks right along with it, providing a path for moisture to enter the porous concrete foundation and seep into the basement. This seepage is disastrous if it occurs beneath a finished basement wall, where the moisture cannot dry out and remains hidden. Mold will be the result.

We next recommend you apply a dimpled exterior drainage plane over the parge layer. Products include Delta®-MS (888-433-5824; www.deltams.com), J-Drain® (800-843-7569; www.j-drain.com), or geosynthetic clay liners made by Cetco (800-527-9948; www.cetco.com/LT/GCL.aspx). See chapter 12 for details of exterior drainage mats.

Internal Waterproofing

On the inside basement wall, waterproofing materials often separate from the foundation when moisture collects behind the waterproofing layer. This does not occur, however, when Xypex® penetrating concrete and masonry sealer[259] is applied because Xypex® penetrates one to four inches, creating a bond that does not blister off from water pressure underneath after a few months as traditional concrete sealers often do. Xypex® is resistant to capillary intrusion of liquid water but is water vapor-permeable, a combination of properties we strongly encourage. It can be tinted in various colors. When applied over a clay plaster coat covering a thick material foundation wall, it creates a smooth and attractive wall finish that is fully breathable. Both Xypex® and American Clay® brand clay plaster are nontoxic. Leaving the foundation wall surface exposed (but finished) is crucial in our opinion to maintaining a mold-free basement. We discuss our foundation and basement protocols in more detail in chapter 12.

[259] Information is available from either the Xypex Corporation (800-961-4477; www.xypex.com) or Green Building Supply (800-405-0222; www.greenbuilding supply.com).

Chapter 10. Breathable Options for Thin-Wall Construction

10.1 Introduction

As building biologists we base our health-promoting protocols on the use of thermally massive, "thick-wall" breathable envelopes. While this approach provides the healthiest, most cost-effective and comfortable walls and foundations, some homeowners and builders will choose a stud frame home with insulation. For those who make this choice, we offer alternatives to the traditional approach using vapor barriers, fiberglass batt insulation and plastic exterior house wrap. Our alternative approaches are designed to give you as healthy, as mold-free and as energy-efficient a wall as possible. The benefits from these alternatives are enhanced when you use cement-bonded wood fiber wall forms for your basement foundation instead of poured concrete or concrete blocks and include a waterproofer and dimpled membrane as an exterior foundation wrap.

10.2 Wood Framing Alternatives

If a wood frame home is desired it can be adapted to be ecological, economical and healthy. We recommend the following general points:

- Use no metal studs. Steel studs can carry neutral current running on the ground system, which causes magnetic field exposure throughout the house. This occurs when the grounding system, which carries some degree of current in most homes, comes into contact with the metal studs at two or more points in the wall, such as metal outlet and switch boxes and lamp fixtures. Electrically sensitive people are bothered by this, and we believe that everyone is adversely affected to some extent. We recommend that you avoid metal studs at all costs.

- Avoid chipboard, particleboard and imported plywood. This is due to outgassing of glues and formaldehyde. If you do choose wood products, the more acceptable ones are exterior or marine grade plywood, MDF and interior grade plywood made in the USA by members of the American Plywood Association. These contain phenol formaldehyde, which is more chemically bound than urea formaldehyde, and are considered acceptable materials by building biologists. Phenol formaldehyde outgasses quickly at the beginning of its life, and generally not thereafter. Chipboard, particleboard and imported plywood, on the other hand, all contain urea formaldehyde, which is not strongly chemically bound and separates relatively easily into urea and formaldehyde. These materials release free formaldehyde into indoor air for many years.

- Also, avoid oriented strand board (OSB) for structural reasons. The experienced, "green" builders at Gimme Shelter in Amherst, Wisconsin (715-824-7200), have found that OSB does not hold fasteners very well over time if it gets wet from rain during construction or from a water leak later on. This is particularly true when OSB is used as bathroom subflooring around toilets that develop a leak.

- Many builders nail horizontal furring strips onto the interior surface of vertical studs. This considerably reduces thermal bridging (conduction) of heat and cold between interior to exterior wall surfaces through wood studs. This significantly increases R-value because rather than having potential heat loss through every stud, you reduce the heat loss to a patchwork of small squares at the location where horizontal furring strips cross a vertical stud. Create an air gap between cladding and external sheathing, as discussed in detail in chapters 7 and 9. Cap this air space above and below with screen mesh to keep insects out.

10.3 Magnesia-Based Sheeting on the Construction Site

Magnesia-based, fiberglass-reinforced "low-tech" composite boards, composed of magnesium oxychloride ("MgO/Cl"), fillers and additives, were introduced in chapter 8 as an alternative to standard plywood and OSB for sheathing, wall board, subfloors and roof decking. They are in wide use in China and interest in North America is rapidly growing. Here we present practical information on their use on the job site. For simplicity we will henceforth use the informal term, "MgO" sheeting, to refer to these building products.[260]

MgO boards can be used in thicknesses that are smaller than conventional materials. For example, a ⅜ inch MgO board can take the place of ½ inch drywall. In applications where structural ratings are required then "same thickness" sizing is recommended.

Most wood frame walls, up to 98% in George's opinion, do not need external sheathing to help hold the building up. Builders often self-brace a frame to avoid this when using plywood or OSB by using "let-in" braces and engineered bracing at corners. MgO boards can help brace a building when used as sheathing, just as OSB and plywood can. All MgO boards currently on the market in the U.S. will

[260] It should be understood that while MgO is the chemical formula of one of the primary ingredients in the magnesia-based cement used to bond the boards, magnesium oxide reacts with another raw material, magnesium chloride, resulting in a building material that is composed rather of magnesium oxychloride (MgOCl) plus fillers and additives. There is little or no MgO phase remaining in the final product. Nevertheless the designation "MgO" is frequently used as a label by builders and contractors familiar with these sheeting products.

provide this support, but currently only DragonBoard (866-447-3232; www.dragonboard.com) has the documentation at this time to prove it.

MgO boards are perfect as "wet board," that is, wallboard that can withstand exposure to moisture and resist mold. Uses include behind and underneath sinks, tubs and showers stalls, in laundry rooms, in garages and in mechanical rooms. These boards are also excellent if you choose to follow the protocols we recommend for waterproofing your foundation and finish off a basement as they resist mold, and represent the only material we would recommend if you plan to do this. (Bear in mind that we still strongly urge you to resist covering foundation walls with anything other than tinted clay and Xypex®, because if you install a false wall you do not know whether moisture appears, and it will not be able to dry out.)

Strong-Enviro Board® is one of the best all-around choice according to George, especially if screwed over a wood frame. Although George represents both companies, he points out that Strong-Enviro Board® is substantially lighter in weight than many of the woodchip-filled MgO boards, cuts perfectly and is a precision board. Unlike other brands it also has a sound-absorbing perlite-like core.[261] Strong-Enviro Board® boards are pre-beveled and pre-drilled to accept screws and self-adhering tape. On the other hand, DragonBoard has conducted more testing of its board. In general George recommends Strong-Enviro Board® for residential construction and DragonBoard® for commercial use when testing and industry certification is more necessary.

All the board products come with "tapered" edges on request at no additional charge, so that thin fiberglass tape can be flushed into the recess provided and then mudded over with a nontoxic joint compound. Outdoors George recommends using an exterior joint compound such as Synko Exterior Spackling Paste® (800-421-1004; www.synkoproducts.com). This is premixed and can be used right out of the can. Alternatively, when one will be using magnesium phosphate stucco, a site-mixed "MgO/P" mix can make an even more durable, more stucco-compatible joint compound, to be blended to exact specification for each project.

George generally recommends applying one coat of mineral silicate paint, discussed in section 9.7 above, directly to the exterior of MgO/Cl boards. In most climates this is sufficient as a weather barrier and creates a strong, breathable mineral-to-mineral bond. An alternative is to create your own custom magnesium/sand mastic by mixing one part magnesium phosphate from the Bindan Corporation (630-734-0277; www.bindancorp.com) or other suppliers, one part white Portland cement, and one part "100-grit" fine grain (sand blast) sand. You can create as smooth a wall surface outside as you do inside, which is a trend that is now popular as an exterior finish. Contact George Swanson at www.geoswan.com for details on custom magnesium oxide/sand mixes.

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[261] Perlite (see http://en.wikipedia.org/wiki/Perlite) is a naturally-occurring amorphous volcanic material that has the unusual property of tremendously expanding in volume when heated to the point that its waters of hydration escape. The resultant density is typically in the range of only 30-150 kg/m^3. Paul Danneman, Vice-President of Sales at the company, told us that the "popcorn rock" they use is a similar but different mineral.

Finally, MgO boards can be easily cut with "cement shears," such as the heavy-duty half-inch variable cement shears made by Dewalt. They are available for just over $200.[262] These shears fit in your holster and cut MgO boards cleanly without dust. Furthermore, the Canadian MgO board manufacturer, Magnesiacore Inc., the company that primarily serves the high-end commercial market, has a wealth of information on their website (www.magnesiacore.com) on the use of their brand of MgO boards. This includes some excellent installation videos.

10.4 Alternative Wood Frame / MgO Board Protocol

George Swanson has developed a unique protocol that combines MgO boards and cotton batt insulation with wood-frame construction to provide a breathable, affordable alternative to cement-bonded wood fiber and other low density blocks. His protocol provides many of the features of breathable, thermally massive f in a thin-wall version. Compared to standard plywood or OSB sheathing, dry wall and fiberglass insulation, George's approach greatly reduces the chance of mold and structural damage from water intrusion, the most prominent problem in conventional wood-frame construction today.

The protocol involves the following steps:

1. Spray the wood frame with a thin layer of magnesium phosphate, kaolin clay and borate.
2. Embed any stud-to-concrete framing in a thick preserving bed of magnesium oxide and clay.
3. Install magnesium boards on the outside of the wood frame as sheathing.
4. Fill the cavity with cotton insulation, which has the capacity to dry out through the breathable MgO boards inside and out. An alternative to cotton is to spray a mixture of wet magnesium oxide, clay and borax along with cellulose into the cavity.
5. Install magnesium boards on the inside of the wood frame in place of drywall.
6. The inner wall is finished with natural plaster, and the exterior with mineral stucco paint, discussed below.

The ratio of magnesium to clay should be as follows: Blend 30% magnesium phosphate with 68% bentonite or kaolin clay, and add 2% borax (essentially one third magnesia-based cement to two thirds clay with a pinch of borax).

For exterior applications the sheets can be stuccoed directly with an ultra-thin single layer of all-natural mineral-based stucco paint. You can also skillfully apply a single coat of magnesium phosphate and sand stucco, mixed on site, directly over fiberglass-seamed joints. This greatly reduces steps and costs in traditional construction. See above for details.

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[262] See http://www.dewalt.com/us/products/tool_detail.asp?productID=15509.

10.5 Cotton Batting as an Insulation Alternative

Cotton batting is one of the recommended insulation materials for George's MgO board protocol for wood-frame construction. We also feel it is a viable alternative to fiberglass insulation in a wood frame home, particularly if one uses an airtight drywall approach (using aquarium grade nontoxic caulk). It is also a healthy and effective alternative to fiberglass as a thermal and acoustic insulating material in ceilings, interior partition walls and floors in a home built with a thermally massive envelope.

The advantages of cotton batting over fiberglass include:

1. Ease of installation and safety for installers.
2. Derived from a natural, renewable, non-petroleum-based resource.
3. The ability to dry when it becomes wet.

Regarding this last point, George reports that if you place cotton in one hand and fiberglass in the other and spray water on each, the cotton dries in three to four minutes while the fiberglass can take several hours to dry. As discussed in chapter 7, in hot weather, whenever the outdoor relative humidity exceeds 15-20% (which is most of the time in all parts of the country except for the desert), fiberglass insulation within a wall stays damp. Indeed the fiberglass never dries all summer long.

The excellent openness of cotton batting to moisture diffusion is complemented by the organic fiber's strongly hygroscopic nature,[263] although low mass limits its overall capacity for moisture vapor adsorption/desorption. Breathability of the lightweight building envelope can be enhanced by "misting" all surfaces inside the wall, including the insulation, with a blend of magnesium phosphate, clay and borate, as presented in the previous section. In fact, we recommend this step, which adds a small measure of moisture exchange capacity, for all conventional frame construction and insulation applications.

Why is this necessary on a practical level? If wind-driven rain penetrates stucco and MgO sheathing on a wood frame wall, the moisture will dry out more readily if cotton or tightly packed dry cellulose insulation is used rather than fiberglass. You also do not want to use a vapor barrier with cotton insulation. If so you run the risk of promoting condensation within the batt, which will diminish the performance of cotton as an insulator.

These insulating materials do not lose their insulating capacity when they become damp like fiberglass does. Open-cell polyurethane spray-in-place foam

[263] Orme Masson, E. S. Richards, "On the Hygroscopic Action of Cotton," *Proceedings of the Royal Society of London. Series A, Containing Papers of a Mathematical and Physical Character*, Vol. 78, No. 525 (Dec. 20, 1906), pp. 412-429. Article available at http://links.jstor.org/sici?sici=0950-1207(19061220)78%3A525%3C412%3AOTHAOC%3E2.0.CO%3B2-S.

can also be used, as the face of the foam meets code as the vapor barrier. We prefer open-cell to closed-cell spray-in-place foam because open-cell is more flexible and will expand somewhat and adhere to wood studs over time. This avoids the shrinking away from studs and resultant air infiltration that is now reportedly occurring many years after installation with more rigid, closed-cell, spray-in-place foam.

The one disadvantage to cotton, cellulose or spray foam infill is that by itself it does not provide any degree of thermal mass, and for that and many other reasons we recommend thick wall materials for those homeowners who can afford them. The exception would be the use of cotton insulation with MgO panels used as sheathing and wall board and the spraying of wood studs with magnesium phosphate and clay. This provides a hefty amount of thermal mass for a wood frame house, and the cotton is a breathable, mold-resistant, and (through the use of borate) fire-rated insulation.

Bonded Logic in Arizona markets “UltraTouch®” (480-812-9114; www.bondedlogic.com). As we prepared this chapter for publication in February 2008, we discovered that another company, InsulCot in Texas (806-777-2811; www.insulcot.com), has recently entered the market. Bonded Logic uses a random fiber orientation process in its manufacturing process to create multiple air pockets, as opposed to other companies once in the business that layered their cotton. Previously manufactured cotton insulation product was denser and did not dry out as fast as UltraTouch®, which led to the growth of mold. This is avoided in UltraTouch® by its random fiber orientation process.

With all the benefits over fiberglass, cotton’s one potential downside for chemically sensitive people in our opinion is that the stock of fabric cuttings provided to manufacturers can be saturated with pesticides and herbicides in the growing process, particularly when cotton is grown in Mexico.

To address this issue we spoke with Scott Tonkinson, who was the Marketing and Advertising Manager for Bonded Logic, makers of UltraTouch® cotton batting. He said his company is able to remove most of the pesticides present in the original cotton through several steps in the manufacturing process, described below. This has been confirmed through outside testing including by a team of German researchers for Bosch and Siemens Hausgeräte GmbH that purchases UltraTouch® to insulate their high-end dishwashers.

Tonkinson said that Bosch and Siemens Hausgeräte is a very environmentally-friendly company that adheres to strict European standards, and that they would not use Bonded Logic’s cotton unless it met their stringent requirements for nontoxicity.

Bonded Logic starts with cotton that is sorted, pre-washed and broken down into its original fiber by its suppliers. They then wash the cotton a second time and saturate it with straight borate (minus ammonium sulfate) as a fire protector and natural fungicide.

The cotton is then thermally bonded at 400 ˚F, which locks the fibers together to produce a full sheet of insulation. They also add 10% polyolefin copolymer, a nontoxic garment polyester used as a binder to give the cotton memory. This allows it to rebound to its full loft for insulating purposes from its compressed state after shipping.

Scott Tonkinson said the 400 ˚F thermal bonding process "bakes out" most of the pesticides, as confirmed in testing by the ICBO and other agencies. His company claims UltraTouch® has low emissions of VOCs and pesticides and is very safe for chemically sensitive homeowners, and safe for installers as well. Scott writes:

> I spoke with Tod Kean, our General Manager, and he said that we do not have formal testing as to any percentages of possible chemical residue that would exist from the cotton fibers as they arrive at our plant. However he also mentioned that the majority of natural fibers used for our products are the highest quality denim or clothing fibers that are worn daily by millions of people and that our cleaning process as well as thermal bonding process provide for an extremely clean fiber.

10.6 Cellulose Infill Insulation

Cellulose infill is another healthy alternative to traditional fiberglass batt insulation that provides a number of advantages, particularly when wet-sprayed in a wall cavity or packed tightly in its dry form.

Cellulose has several properties that set it apart from fiberglass. From the website for the Cellulose Insulation Manufacturers Association (CIMA), these include:[264]

1. Cellulose insulates better. It not only offers more heat transfer resistance per inch than other fiber insulation materials, it also seals the home against air infiltration better than other fiber insulations.
2. Cellulose insulation productively recycles a waste product that presents communities with a serious disposal problem.
3. Cellulose insulation saves more energy when the energy required to make the material – "embodied energy" – is figured into total energy savings.
4. Cellulose insulation makes homes safer by slowing the spread of fire.
5. Cellulose insulation makes efficient use of natural resources.

According to the CIMA, cellulose has a favorable R-value of 3.6 to 3.8 per inch, but as is the case with thick-wall materials, comparing R-values of materials is often not valid when they differ in how they behave. Materials like cellulose have the ability to prevent the infiltration of cold air, which can represent 20 to 40% energy savings in studies comparing cellulose-insulated homes to fiberglass batt-insulated homes.

[264] See http://www.cellulose.org/pdf/cellulose_benefits/heres-why.pdf.

Why is cellulose superior to fiberglass in preventing cold air infiltration? As we discussed in chapter 17, fiberglass in a paper batt does not completely fill the wall cavity, leaving cracks and crevices for cold temperatures to penetrate the wall. According to the CIMA website under the heading, "Cellulose vs Fiberglass":

> Batt insulation cannot be fitted tightly around wall inclusions, such as pipes, wires, and electrical boxes. Cutting a batt to fit, and pressing it around plumbing and electrical details creates gaps and depressions that seriously degrade the thermal performance of the wall. Dense-packed or sprayed cellulose insulation fits around everything in the wall, creating a tight, uncompromised thermal barrier.[265]

Furthermore, cellulose has a much higher fire rating than fiberglass, up by 22% to 55%, and it increases the fire resistance by 26% to 77% compared to a wall that contains no insulation whatsoever.

As noted above, cellulose is also more ecological to manufacture because it is made with a recycled product and contains 50 to 200 times less embodied energy than fiberglass or plastic foam insulation. It is also possible to obtain cellulose material made with uncirculated newspaper stock, some of which contains soy-based inks. This reduces toxic exposure to vapors the newsprint may have been exposed to in customers' homes and the use of petroleum-based inks by the newspaper printer. Check with your local distributor for availability.

One downside to the use of spray-in-place cellulose is that it does have a moisture drying period of up to several days. This can delay construction schedules, but it is absolutely necessary to wait for full drying before applying wall board so as to avoid mold. If one uses MgO boards for sheathing and drywall without a vapor barrier, which is a very beneficial combination, there is less chance of a problem.

George Swanson reports a new development in the evolution of spray-in-place cellulose. This involves magnesium phosphate, clay and borax mixed with the cellulose right at the spray nozzle as the cellulose is wet-sprayed into the wall cavity. The substitution of magnesium phosphate for chemicals commonly used by cellulose installers provides many beneficial properties. These include added thermal mass for the wall contents and further decreasing the already low chance of mold in a cellulose-insulated wall. George is making this knowledge available through Substance Distributing Co. at www.substanceproducts.com.

10.7 Magnesia-based Mineral Blown-in Insulation

Magnesia-based mineral blown-in insulation known as air krete® (315-834-6609; www.airkrete.com) was discussed in section 8.8 as one of the Healthy Alternative Cements. This product is similar to wet cellulose mixed with

[265] See http://www.cellulose.org/cellulose_mold.html.

magnesium discussed above, in that it fills all crevices in each wall cavity when sprayed in.

Air krete calls their product, "a ceramic cement spray-in foam material." As discussed in section 8.9, it has the following characteristics, according to the company's website:

1. Nontoxic and environmentally friendly materials
2. Resistance to mold growth at 75% and 95% relative humidities (according to testing following the ASTM Guideline D 6329-98 (1))
3. Fireproof with zero flame spread, fuel contributed and smoke density factor at 30 minutes
4. An R-value of 3.9 per inch at 75 ˚F (according to testing following the protocol requirements of ASTM C-518.76)

The cost is $.30-$.50 per board foot (12"x12"x1" thick) installed (roughly double the cost of blown-in cellulose).

Like wet spray-in-place cellulose above, there is a moisture drying period required with air krete. There is also some degree of friability when the material dries unless it is installed according to strict manufacturer guidelines, but recent developments at the company and elsewhere are in the works to produce a less friable product.

More information regarding air krete® mineral blown-in insulation can be obtained by calling R. Keene Christopher at 315-834-6609. Air krete® is now being installed in the upper Midwest by GreenKrete Building Systems in Fairfield, Iowa, 641-472-1507, www.greenkrete.com.

Chapter 11. Slab

11.1 Introduction

A modern concrete slab built over a vapor barrier (retarder) and rigid board insulation is generally thought to be a benign and necessary part of home construction, yet it can be fraught with problems that affect health. Chief among them is the production of mold, caused by the tendency of Portland cement to hold and retain moisture. There is also the fact that most sub-slab vapor barriers (retarders) fail to contain soil gases due to breakage of the plastic during the concrete pour. Hence radon is a concern.

Yet mold and moisture content is only one health problem caused by a concrete slab. First of all, they outgas volatile organic compounds such as residual acrylic or epoxy precursors when the latter are added to the mix. Second, for one or more possible reasons outlined in section 8.6, these floors behave like "energy sinks." They have been known to promote a phenomenon that we do not really understand, but have nevertheless witnessed among clients, namely the occurrence of chronic fatigue and other illnesses in occupants who stand, sit or sleep on or near them. We speculate that this is related to the high electrical conductivity of moist concrete slabs and their ability to withdraw electrons from the bodies of occupants living or working over them. *[In the published edition we hope to develop this line of reasoning. –Ed.]*. As a result of these and other health issues, we offer alternative slab protocols that promote breathability while maintaining thermal performance and avoiding mold.

11.2 Benefits of Using Low-Density Fiber-Cement as a Sub-Slab Material

For a mold-free breathable basement or at-grade slab, we recommend that you:

1. Place one to four inches of pre-crushed chips (typical dimensions one inch long by ⅜ inch wide) of Durisol® or Faswall® low-density fiber-cement over a level, one to two inch layer of lightly compacted bed of sand, fine gravel or sandy loam on bare soil. This is a breathable insulating layer under the slab that equals below-slab rigid board without the downsides of rigid board and vapor barriers (retarders). The colder the climate, the thicker the layer should be, but even one inch provides the all important thermal/moisture break. (Both manufacturers listed in section 8.8 can provide inexpensive pre-crushed or new stock of chips in 2 cubic yard "Gaylord" bags.) This also provides a capillary break.
2. Broadcast or "dust" over the chips with about a quarter inch layer of Portland cement.
3. Lightly hose over cement until wetted.

4. Allow to cure overnight. Cement will be barely able to be walked on but will be stable enough to allow you to do the following:
5. Set forms.
6. Add breathable landscape "filter cloth" in place of a vapor barrier (retarder). This serves two functions. First, it slows down the concrete drying process, thus preventing cracking. Second, it prevents loose chips from falling into the dug out footing and beam pit.
7. Pour concrete slab.
8. If you are pouring an at-grade slab in areas prone to flooding, provide a French tile drainage system around the perimeter of the slab that drains to daylight or an external sump pump to avoid standing water around the perimeter of the house.
9. Once cured you may lay cork, tile, colored concrete, magnesia-based terrazzo or wood finished flooring. We do not recommend any carpeting in basements. Use nontoxic concrete coloring and sealers, such as from the AFM Company (619-239-0321; www.afmsafecoat.com). Note also that Durock®[266] and Wonderboard® are similar to Durisol®, except denser. They contain a nylon mesh and are both available in 3′ x 5′ x ¾″ sheet form. These products have an excellent reputation as underlayment for a tile, cork or wood floor. The protocol above is essentially a "poured in place" version of these boards

For extra EMF protection consider laying MgO board (see section 8.11) on top of the concrete slab to further mitigate the effect of "concrete sickness." Use Strong-Enviro Board® or DragonBoard®. This lessens the deleterious health effects of Portland cement known as "concrete sickness," described below. It also allows the slab to stay dry compared to a traditionally constructed concrete slab floor with a vapor barrier (retarder) underneath, which is constantly moist. Exposure to sub-slab moisture has been shown in our profession to aggravate arthritis.

An alternative to the above is to make a wood chip terrazzo slab with 60-70% cement-bonded wood chips and 30-40% concrete by volume. This is more dense than Durisol® (which is 85% and 15% respectively) and can be poured in place as a cement-bonded wood chip terrazzo rather than as a solid concrete slab. This floor requires considerable skill to achieve an attractive surface but will allow moisture to breathe through much better than a conventional slab, thereby avoiding mold, especially if the 1-2 inch cement-bonded wood chip thermal break is provided by following the protocol above.

Once you have set the forms (through step #5 above), do the following alternative steps:

1. Mix wood chips 60-70% with concrete 30-40% by volume.
2. Tamp and trowel into place as level as possible.

[266] See http://www.cgcinc.com/home.asp?nav=52&mkt=30&bc=2.52.

3. You can also dust a thin layer of magnesia-based cement on top of the concrete slab, as described above.
4. Once slab is cured, lay such solid surface flooring as cork, tile, terrazzo, or wood as optional finished flooring.

You need to learn how to do this. The cost is about 40% more than a conventional floor. Call George Swanson for details (512-653-8624; gps@flash.net). George says, "Healthy slabs do not just happen, they are designed!"

To ensure even more "breathability" to the underside of the slab, you can also "vent" the edge of the slab in line with the one to four inch chip layer using two inch diameter by twelve inch long tubes placed every four feet and filled with cement-bonded wood fiber chips. From the outside of the slab edge, the opening of the tube is simply stuccoed over with breathable (magnesia or lime) stucco at the same time the rest of the wall above is stuccoed.

If local code does not allow using chips of low-density fiber-cement for under slab insulation, a possible alternative is a layer of washed river rock (½ to ¾ inch) with filter paper over the top instead of a vapor barrier (retarder). This will create a "breathing" layer. Another substitute, if allowed, is crushed windshield glass. But keep in mind that neither of these options offers all of the following advantages of the wall form chipped low-density fiber-cement.

The first benefit of using low-density fiber-cement chips beneath a slab is that it acts as a capillary break allowing it to stay dry and mold-free. Conventional slab construction, on the other hand, uses a polyethylene vapor barrier (retarder) with or without extruded polystyrene as insulation, which can produce mold growth on both sides of the barrier within a few months of construction. This is because of dampness within the soil, which is always trying to escape and "breathe" to the air above. Conventional construction tries to impede this natural flow of moisture, which creates problems. You see evidence of this when you crack open a conventional slab and examine the underside, which George has done, often revealing patches of mold growth.

Under most conditions, wherever you have air you have water vapor. All concrete slabs have minute cracks, which allow water vapor and soil gases, including radon, to escape into the basement at very low rates. George has often found what he describes as "a moldy goo" on both the upper side and the lower side of a vapor barrier (retarder) placed under a concrete slab. The vapor barrier has the potential to bleed on either or both sides, depending on the shifting pressure, humidity and temperature gradients above and below the slab. This potential is realized when the vapor barrier gets broken during the concrete pour. The resultant mold spores and gases that come through breaks and cracks in the slab are continuously inhaled by occupants, negating the intention of the barrier.

The cement-bonded wood fiber material placed underneath the slab assists in moisture removal from the less permeable Portland cement in the slab by a mechanism involving both diffusion and adsorption of water vapor. The high vapor permeability and equilibrium moisture capacity of low-density fiber-cement were documented in sections 6.3, 6.4 and 8.8, and if you want to understand diffusion and hygroscopic adsorption we urge you to revisit those sections in chapter 6. The fiber-cement's hygroscopic internal surface provides a reservoir to pull moisture away from the slab and store it until it has a chance to drain away over time. By this mechanism the slab moisture content is reduced.

The air within and around the chips of fiber-cement also acts as a thermal barrier. In answer to the question, where is the insulating layer in this alternative protocol, George states, "The thermal break created by the few inches of broken Durisol® or Faswall® chips under the slab *is* the insulation." No other insulation is needed and should be avoided, as you run the risk of causing mold if you use rigid thermal board.

Low-density fiber-cement as a sub-slab material is also ideal when water pipes are laid in the slab for in-floor radiant heat, such as with Wirsbo® plastic tubing. The thermal break provided by the chips that lay below the in-floor pipes helps radiate heat upwards. Lay the chips, then the pipes, then the slab. This protocol re-radiates heat upwards.

11.3 Use of an Air Gap Membrane under a Concrete Slab

One alternative to using thin polyethylene plastic as a vapor barrier (retarder) is to use one of the air-gap drainage membranes described in chapter 12. Typically measuring 24 mils, these membranes are thicker and much stronger than most poly sheets used as a vapor barrier, which are only 6 mils thick. The sturdy air gap membrane will easily withstand a concrete pour while the traditional 6 mil vapor barrier (retarder) is usually punctured, defeating its purpose as a vapor and radon barrier.

Once poured, if there were no membrane of some kind underneath it, the moisture contained in the soil would reach a state of equilibrium with moisture in the slab, even through puncture holes in a standard sheet of poly. When you install an air gap membrane under the slab, however, the slab no longer takes up soil moisture because the membrane acts as a capillary break. Soil moisture will condense onto its underside rather than be absorbed into the concrete by capillary action through torn plastic. This keeps the slab dry and mold-free.

Furthermore, the membrane does not promote drainage. Rather the chips of fiber-cement underneath provide the drainage.

An air gap membrane is particularly useful in the case of a high water table, where chips of fiber-cement would be wetted by the high moisture content of the soil and have no remaining hygroscopic capacity to pull moisture away from the slab by adsorption. In such cases, a mechanical sump pump can also be used, carefully sealed to avoid the escape of radon gas that could be present.

Finally, the air gap drainage membrane creates an air space under the slab when a drainage membrane is chosen that has a geotextile mesh bonded to the flat tops of its dimples. The membrane is installed with the dimples facing up. The geotextile filter prevents the poured concrete from occluding the space between the dimples, protecting the air space that is created under the slab. If an HVAC system is used to heat and cool the house, then air pressure within the basement pushes moisture downward through microcracks in the concrete.

11.4 Radon Mitigation

Radon is a serious problem in many sections of the country, accounting for more deaths from lung cancer than any other cause except cigarette smoking. It is a silent health threat, in that radon is odorless and colorless. It is a soil gas derived from the slow breakdown of radioactive rocks in the earth. When it enters the lungs, it is a carcinogenic irritant. People living in houses built before the last decade or two had less of problem with radon until builders began constructing tighter and tighter homes to conserve energy. Now radon mitigation systems are mandatory in many states for new construction. We present adjunctive approaches to radon mitigation, as recommended by George, using breathable basement and slab-on-grade floors.

To begin with, a building site that measures within acceptable limits for radon before construction will not get worse with a breathable slab and basement floor. A slab (with a vapor barrier) built over a site that may measure only moderately high in radon can produce high readings once the house is built because the vapor barrier (retarder) concentrates the emissions to the drain area and the barrier may also break when the concrete is poured. In addition to mandated radon mitigation systems we believe it is also helpful to build in breathability to reduce the concentration of radon gas in the first place.

The understanding is that if a home is generally well ventilated, as with breathable walls that add a slight degree of fresh air exchange with the outdoors (along with natural ventilation from leaky windows and doors and loose construction, especially in older homes) and the possible use of an air-to-air heat exchanger, a topic to be discussed in section 14.3), one does not need to be so concerned with concentration of radon gas in the living space (though we still recommend testing before and during occupancy). Before the 1980s, homes were much less airtight—especially lath and plaster homes built in the early part of the 20th century—and concentration of radon gas was not much of a problem. In super-tight homes, concentration of radon gas has become a problem. On top of that, too much ventilation, such as from a high cfm (cubic feet per minute) kitchen exhaust fan, can draw radon up into the living space by means of what is known as the “stack effect.”

Historically radon testing of the soil had been performed around the country at proposed building sites before installing a basement slab. More recently this has been shown to be ineffective at giving a definitive prediction of radon gas levels in a finished dwelling. Therefore radon testing is recommended once construction is completed, prior to move-in.

New building codes in many states now mandate the installation of at least a passive radon mitigation system. That includes sealing the slab and providing sub-slab gas collection tubes and piping to the roof. This allows the slight exhaust of gases through the passive system. If testing shows that this is not enough at keeping measured levels within safe limits, a fan can be added in the attic once testing is performed.[267]

We suggest incorporating an air-gap drainage membrane as an adjunctive radon control strategy, thereby creating a barrier to radon gas infiltration. The membrane still allows some degree of breathability of the slab through the gap provided among the dimples on the upper surface of the drainage membrane lying beneath the slab.

11.5 Strategies to Mitigate "Concrete Sickness"

[This section is in the midst of being carefully rewritten and our understanding of this rather nebulous topic is evolving, so please don't take our speculation too seriously! –Ed.]

Placing low-density fiber-cement chips beneath a concrete slab provides a buffer against so-called "concrete sickness." We first described this phenomenon in section 8.6, Concrete Made with Portland Cement and section 6.10, Natural Materials and Subtle Energies. One theory says that a large amount of cement-bonded cellulose laying under the slab provides what Dr. Phil Callahan has called a balanced diamagnetic/paramagnetic interface, in this case applied to the relationship between the mineral and the wood chip contained within chips of fiber-cement lying beneath the slab floor. The mineral refers to proprietary ingredients in both Durisol® and Faswall® wall forms. This is similar to the balanced "push-pull" dynamic created between hard bone and soft cellulose tissue in the human body, as described in our section Natural Materials and Subtle Energies, above.

To review from section 8.6, in the concrete manufacturing process the natural crystalline waters of hydration are lost from the mineral raw materials during the prolonged heat treatment to make the clinker at 3000 ºF. Building biologists such as Hubert Palm, Helmut Ziehe and George Swanson have observed that concrete adversely affects occupants when they stand on it, causing fatigue. One of Palm's explanations for concrete sickness was that the mineral crystals lost their beneficial "life qualities" (subtle energies) during their dehydration because the latter are stored in the crystalline water. When low-density fiber-cement is placed under the slab, however, Helmut and George speculate that concrete within the slab pulls electrons from the cellulose of the cement-bonded wood fiber chips below to balance its so-called "unstable" electronic charge, rather than from the feet of humans standing above. Whatever the mechanism, using chips of low-density fiber-cement beneath a traditional concrete slab has been shown to relieve fatigue and arthritic aggravation. Adding a thin layer of magnesia-based cement or placing a layer of MgO sheeting *over* the concrete slab likewise reduces this deleterious effect, a technique described in section 8.11.

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[267] Our profession recommends the use of flexible metal clad (MC) cable rather than plastic-jacketed Romex® wiring to the fan so that occupants in bedrooms near the path of the wiring will not be exposed to electric fields while sleeping. These fields extend ten or more feet from all plastic-jacketed wiring, even through wall board. Be sure to use grounded metal cable, either flexible or rigid.

In summary, chips of low-density fiber-cement placed under a cement slab provide:

- A thermal break
- A capillary break against liquid water ("rising damp")
- A hygroscopic, "breathing" layer for the concrete slab above it, decreasing the moisture level of the concrete
- A counterbalance to the unhealthy electron flow within the concrete slab lying above it. (Note the electrical conductivity of the slab decreases with dropping moisture content)

Adding a thin, nonconductive layer of magnesia-based cement on top of the slab prevents electrons from being drained from the people above it.

Lastly, it is advantageous to wait as long as possible after pouring a new slab before enclosing the rest of the house. The excellent natural ventilation provided in the open air allows the concrete to cure and dry out more thoroughly before the building is sealed up, attaining a dryer and less conductive state sooner in its lifetime.

We discuss the various protocols to provide these beneficial sub-slab effects in section 17.1.

Chapter 12. Foundation

12.1 Introduction

At no other place in the design of a house is a "breathing wall" more important than in the design of a basement. This is because basements built the conventional way are fraught with problems, the greatest of which is mold. Crawl spaces are equally problematic, and attempts to seal off moisture and soil gases usually fail, leading to condensation of moisture that cannot dry, which, again leads to mold. Slab-on-grade construction, particularly with a raised plinth, is the best solution from our standpoint, using the protocols provided in the previous chapter for the slab.

If a basement or crawl space is desired, using the following protocols will provide a reduced-mold living and storage environment below ground. Strategies can be used to keep your basement dry and allow it to handle the inevitable water event. As will be pointed out in section 14.2, proper rooftop rainwater management takes care of 90% of moldy basements, and your choice of foundation material and waterproofing also goes a long way in determining whether you will have mold or not.

We would like to thank Dwight Walker of Cosella-Dörken (888-433-5824 ext. 26; dwalker@cosella-doerken.com), makers of the Delta-MS® air gap drainage membrane, for contributing to this chapter.

12.2 Performance Goals

The ultimate goal in any basement or crawl space is to meet the following seven goals:

1. No condensation of water vapor on interior walls
2. No significant seepage of liquid water through the foundation or stem wall by capillary action, including through defects
3. Maintain adequate vapor permeability to allow migration of water vapor to the outside by diffusion, assisted by hygroscopic adsorption/ desorption
4. No wicking of moisture up from the footing ("rising damp")
5. No buckling of basement walls
6. Adequate thermal performance
7. Controlled cracking of a poured concrete slab.

Achieving these seven conditions results in mold-free conditions and maintenance of the structural integrity of the basement or stem wall. The protocol offered outlined below accomplishes these goals by:

- Allowing water vapor to breathe to the outside where it condenses and drains to perimeter footing drain tile
- Preventing water vapor from condensing on the inside of basement walls
- Ensuring any water that wicks in through capillary action evaporates on contact with basement air
- Spreading out lateral hydrostatic pressures against the foundation or stem wall

The recommended components that accomplish these goals include a low-density fiber-cement block foundation or stem wall, a non-asphalt breathable waterproofer, and a dimple mat exterior foundation wrap.

To begin with, wall forms or blocks comprised of low-density fiber-cement are the best choices for foundations, compared to a poured concrete or concrete masonry unit, or CMU, foundation (also known as "cinder blocks"). They provide a dry basement or crawl space by creating a breathable wall.

Figure 43. Construction of a Durisol® basement. (Photo courtesy of Durisol Building Systems Inc.)

Second, the outer few inches of a foundation made with low-density fiber-cement forms can absorb lateral pressures created by freeze-thaw cycles of adjacent soil, particularly when coupled with an exterior foundation wrap. This eliminates internal buckling that is so prevalent with standard concrete foundations, particularly in heavy clay soils.

Third, low-density fiber-cement wall forms save 40-50% of the volume of concrete required for an all-concrete foundation when you use concrete and steel rebar in the wall form cores. Even without the excess concrete found in traditional foundation walls, an overall assembly rating of 2300 psi is still achieved in low-density fiber-cement wall forms.

Low-density fiber-cement wall forms provide sufficient insulation below grade, approximately R-8 without the need for additional insulation. That number increases when you add rockwool inserts, which Tom Van Denend of ShelterWorks recommends to his Faswall® customers. This insulating capacity keeps the inner surface of the basement wall warm, disallowing condensation of moisture. Autoclaved aerated concrete and GreenKrete® block, with their extensive network of air cells, provide similar insulating capacity. This prevents the need for mold-producing rigid Styrofoam® thermal board, inside or out, nor an interior finished wall with fiberglass batts. The numerous air spaces contained within the block accomplish this. In addition, when an exterior drainage membrane is added, the trapped air pockets between the dimples provide additional insulation outside the foundation, keeping the wall warmer and saving energy costs. Be sure that all local codes are met in terms of R-values for the foundation.

Finally, a low-density fiber-cement foundation is more resistant to slight (or great) earth movements than a concrete foundation, because it allows movement on one end of the building while allowing the other end to flex without cracking. This is particularly so if the foundation is dry-stacked without mortar, which is recommended by the manufacturers. Also the wall form material itself is able to absorb lateral pressures and torque better than a poured concrete or CMU foundation wall. Experience has shown that a low-density fiber-cement wall is virtually earthquake-proof. Thirdly, if you use a polyethylene core exterior foundation drainage mat, such as Cosella-Dörken's Delta®-Drain (www.deltams.com), you will have what the manufacturer calls "a slip-joint buffering structure against earth movement."

12.3 Waterproofing with a Cementitious Parging Layer and External Foundation Drainage Membrane

Nontoxic waterproofing methods are available that fully support the ability of a low-density fiber-cement foundation to breathe. These materials also repel moisture pressures inherent in soil, and they avoid toxic petroleum-based ingredients such as asphalt used in conventional waterproofing. Our approach provides a warm, dry, mold-free basement or crawl space with walls that stay straight and true.

The most practical and economical choice for waterproofing is the use of a cementitious-based parging layer, such as Thoroseal®, and a sturdy exterior foundation wrap, also known as a dimple mat or air gap drainage membrane.

Thoroseal Foundation Coating® is a nontoxic, cementitious and water-based waterproofer. Like the mineral stuccos discussed in section 9.7, Thoroseal® is water vapor permeable yet it prevents free liquid water from entering. It is resistant to mold and mildew, unless you use an improper mixture and add too much water. It contains no asphalt and therefore is environmentally friendly and nontoxic for workers and homeowners. Thoroseal® is made by BASF Building Systems, formerly Chemrex (952-496-6000; http://www.thoroproducts.com /products_waterproofing.htm).

The manufacturer claims that the Thoroseal Foundation Coating® does not crack, except as noted below, because the polymer in Thoroseal® gives it good flexural strength and flexibility. The polymer, Acryl 60, is similar to powdered Elmer's Glue® and must be used judiciously, as too much will clog the pores but in moderation it can be safe to use. Using this additive makes the Thoroseal more flexible than the underlying concrete. When small cracks occur in the concrete, no elongation of the waterproofer occurs. If a large crack develops in the underlying concrete substrate then Thoroseal® would not be able to avoid cracking under those circumstances.

As noted in the previous chapter, some builders report that low-density fiber-cement wall forms absorb Thoroseal®, requiring a basecoat. George suggests a standard "brown" coat of three parts sand to one part gray Portland cement, or to simply do a thicker, dryer coat of Thoroseal®.

However if you use a dimple mat along with low-density fiber-cement as a breathable foundation material with a Thoroseal® parging coat, then you will significantly reduce cracks in the substrate. The reasons are two-fold:

1. Low-density fiber-cement and AAC do not crack like poured concrete or CMU does, even when the wall forms or blocks are exposed to the same hydrostatic forces from freeze-thaw cycles.
2. More importantly, air gap drainage membranes actually prevent hydrostatic forces from significantly impacting the foundation wall in the first place, whether it is poured concrete or concrete block, low-density fiber-cement wall form, GreenBlok® or AAC. The air gap membrane thereby prevents the foundation from cracking. This is because it "keeps ground water away from foundation walls" and reduces "stress caused by water freezing and unfreezing in the surrounding soil and settling of soil around the foundation," according to the Cosella-Dörken Company website.

The website goes on to say,

> When there is a leak in the basement, it is caused by hydrostatic water pressure on the wall. The Delta®-MS is a moisture barrier and a drainage layer to stop the water pressure on the wall. The air space provides a drainage path so water can drain to the perimeter foundation drainage system without any hydrostatic pressure.[268]

[268] See http://www.deltams.com/deltams/qna.html. [The quote was modified and updated for us by Dwight Walker, technical representative for the company.]

Exterior foundation air gap drainage membranes have been used for thirty years in Europe and for more than fourteen years in North America, and have been manufactured by the Cosella-Dörken Company of Beamsville, Ontario (888-433-5824; www.deltams.com) since 1995. The Delta®-MS air gap membrane has been evaluated and approved by the National Evaluation Services (NES) in the USA as a stand-alone waterproofing material (NER-591). Copies of this certification are available upon request. Other manufacturers include CETCO of Arlington Heights, Illinois, makers of Aquadrain® (800-527-9948; www.cetco.com/LT/GCL.aspx) and JDR Enterprises of Alpharetta, Georgia, makers of J-Drain® (800-843-7569; www.j-drain.com).

Cosella-Dörken makes a complete line of dimple mats called the Delta® series. Dwight Walker, a technical engineering specialist for the company, generally recommends the Delta®-MS membrane to customers for most common foundation and soil types. For heavier, expansive clay-filled soils he recommends the Delta®-Drain system.

Figure 44. Delta-MS Exterior Foundation Waterproofing Membrane. (Photo courtesy of Cosella-Dörken Products, Inc.)

Both mats have regularly spaced dimples that provide channels for water vapor to condense as free water and flow to perimeter footing drainage tile placed below, at the level of the footing. This includes drying of post-construction moisture. Their website says,

> Most solvent-based foundation coatings keep moisture locked in foundations and basements. Delta®-MS lets the foundation breathe. Because it's right next to the soil, moisture condenses on the colder back side of the Delta®-MS–not on foundation walls.[268]

The Delta®-MS is a one-piece sheet of HDPE plastic that is stapled to the foundation wall with the dimples facing inward. Delta®-Drain, on the other hand, is a two-component drainage system that employs a polyethylene dimpled core and a geotextile bonded to the core for filtration and drainage of groundwater. The dimples face outwards. The geo-fabric and polyethylene layers are bonded by a special thermal process rather than with glue, as used by some of their competitors, meaning the layers are not likely to delaminate under high temperatures or chemical exposure. All of Cosella-Dörken's membranes are tougher than brushed-on coatings and provide waterproofing even if slightly torn.

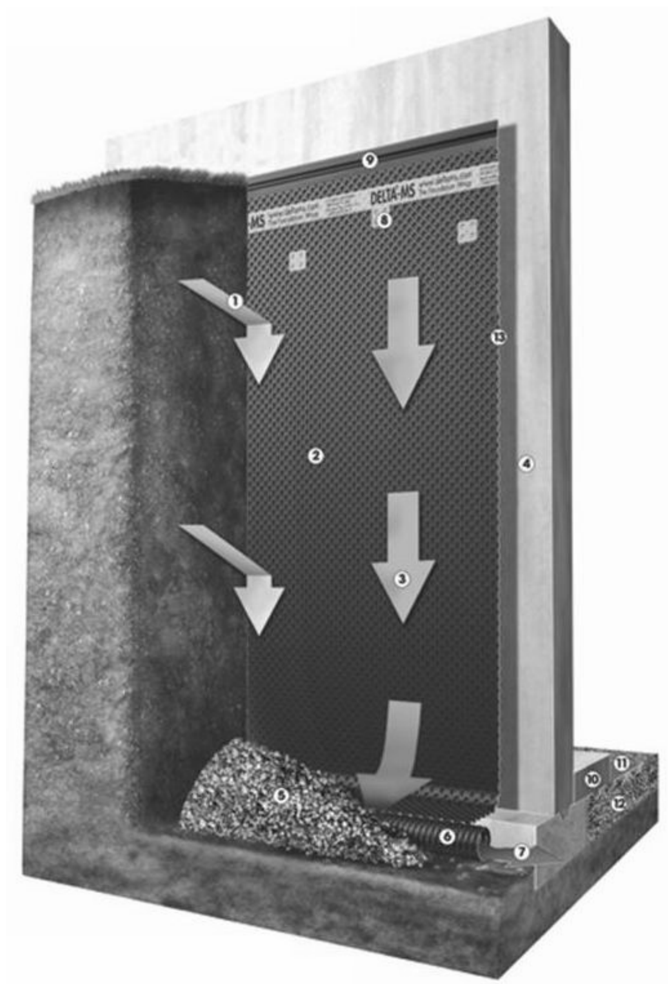

Figure 45. Drainage Pattern with Delta-MS Exterior Foundation Waterproofing Membrane. (Photo courtesy of Cosella-Dörken Products, Inc.)

Cosella-Dörken provides a five-year performance warranty for its Delta®-MS exterior foundation wrap and a 20-year warranty for its Delta®-Drain product, if installed by one of their certified installers. These warranties are for workmanship and materials against any leaks due to deterioration or defects. No other manufacturer of exterior foundation wrap gives a performance warranty to Dwight's knowledge. The company also gives a 20-year product warranty for the Delta®-MS mat if you install it yourself but they are actually designed to last upwards of 50 years, the design service lifespan of many homes in the USA and Canada. Dwight in fact believes the Delta® exterior foundation wrap will last much longer than 50 years.

Delta® foundation wrap is made with industrial grade high-density polyethylene, the same material as in milk containers, which does not outgas or break down over time. The mats come in rolls from 3.8 to 9.8 feet wide and up to 66 feet long, wider than many competitors. They bend around corners and can be softened with a hair dryer. You create a watertight seam by overlapping the ends by two feet, which interlocks the dimples, and by using an adhesive to bond the two ends together.

Figure 46. Installation of Delta-MS Exterior Foundation Waterproofing Membrane. (Photo courtesy of Cosella-Dörken Products, Inc.)

Cosella-Dörken claims that their air gap membranes are rated as a stand-alone waterproofer when applied to a poured concrete foundation, meaning they fully take the place of brushed-on waterproof coatings. In fact they were the first company to have their product approved as both a "drainage and a damp-proofing layer" by the Canadian government, providing a complete waterproofing system. When used with any block wall, however, including low-density fiber-cement, the company advises the use of a parging coat between the outer block and their membrane. According to Dwight Walker:

> To answer your question about the use of Delta®-MS without any other treatment on the walls, this is clearly spelled out in our National Evaluation Service Report Number NER-591 listed under the ICC-ES Evaluation Service. The only exception to this is the preparation of

> "Block Walls" where it is required that all below grade block wall systems be parged with a ⅜ inch thick cementitious parging coat. This is done to fill all of the surface voids in the block and prevent the capillary openings in the blocks from absorbing moisture.

Walker writes,

> To make this parging coat a little more waterproof you can add latex to it, which will still allow for the passage of water vapor moisture through the Durisol wall system and does not stop the "breathability" of the foundation wall, which is the main selling feature of the Durisol foundation system. The use of peel-and-stick waterproofing materials or spray applied over the parging coat is not necessary based on our Delta®-MS NER-591 Evaluation Report, not to mention that most of the petroleum-based waterproofing systems do not support the theory of water vapor transmission through the Durisol system.[269]

The Cosella-Dörken company website (www.deltams.com) summarizes how Delta®-MS protects the foundation:

1. Keeps ground water away from foundation walls.
2. Bridges cracks and gaps in the foundation.
3. Protects foundation walls from cracking due to stress caused by:
    a. Water freezing and unfreezing in the surrounding soil
    b. Settling of soil around the foundation.
4. Ventilates the foundation concrete and allows it to "breathe" and dry.
5. Attracts any condensation. The air gap supplied by Delta®-MS keeps the foundations slightly warmer than the MS membrane. This means moisture wicks out of the foundation and condenses on Delta®-MS, not in or on basement walls!
6. Supplies a path for any moisture that does collect between or on the foundation and Delta®-MS so that it flows down harmlessly to the drain bed.

Furthermore, homeowners and builders are satisfied with the system, particularly because it protects against wetness and mold in basements. A page of testimonials (no longer posted on the website) included the following:[270]

> **What builders say about Delta®-MS**
>
> NO house properly wrapped in Delta®-MS has ever had a leaky basement. That's over 100,000 homes in North America to date (as of autumn 2004) with dry basements. And that's hundreds of builders who've saved the time, money and headaches of call-backs due to wet basements.

[269] Dwight Walker, personal communication with Oram Miller, October 21, 2004.
[270] Testimonials were posted at: http://www.deltams.com/deltams/builder.htm, last accessed November 2007.

Furthermore, Delta® exterior foundation wrap has several advantages over two feet of river or "pea" rock, that is, rounded stones that are often used as backfill against a foundation for improved drainage. The first is cost. The membrane is approximately $0.90 to $1.00 per square foot applied, more affordable than two feet of pea rock.

Secondly, the regularly-spaced dimples in the membrane create less turbulence for drainage whereas stone generates more turbulence because of its irregular shape. In fact, laboratory studies have shown that Delta® air gap drainage membranes consistently provide a higher flow rate and average void ratio than stone when compared column-to-column. This takes into account the percolation rate of the soil. A Delta® membrane eight feet high will drain faster than a column of stone eight feet high and several inches thick.

Dwight Walker also performed tests comparing his drainage membrane with rigid mineral fiber board used as an external thermal and drainage layer. He found that the rigid mineral fiber board stopped draining eight feet down due to compression from soil weight and that it did not meet drainage capacities specified for that depth.

As a result the compression ratio of rigid mineral fiber board is lower than that of Delta® exterior foundation wrap. You would need 5,200 pounds per square foot of outside hydrostatic water pressure from the weight of soil water to crush the wrap and render it unable to drain. The maximum pressures achieved in most conditions may reach 1,800 pounds per square foot at a depth of eight feet when clay soils are saturated with water, but you would never achieve a pressure of 5,200 pounds per square foot at that depth.

What percentage decrease in drainage occurs with the air gap drainage membrane? Walker says the first 10% loss of drainage is important; that is, you want to retain at least 90% drainage of water. In order for liquid water to drain vertically down to drain tile, air must escape. If air does not escape you create an air lock and water will not drain.

Therefore you should allow at least 90% drainage for rigid plastic drainage sheets to work. In addition, the perimeter footing drain tile itself must be sturdy enough to not be crushed under the weight of eight feet of soil. Generally perforated PVC is suitable. It must also drain properly to daylight or be controlled by a sump pump. Failure of the drainage system due to crushed or blocked drain tile is a major cause of moisture intrusion in basements, causing mold.

We recommend that the drain tile be placed below the level of the inside floor slab, so that any water that pools at the drain tile will not penetrate to the inside floor if the drainage system backs up. The drain tile should also not be below the level of the footing, so that water from a back-up would undermine the footing.

In addressing the ability of the Delta®-MS membrane to withstand soil pressures that cause many foundation walls to buckle, Dwight Walker says the killer load comes from a 45-degree angle translational load. This is a combined vector created by the summation of the horizontal and vertical load vectors on the wall, similar to the force needed to move a lawn mower by pushing it both forward and down. This load, if excessive, can act on the sidewalls of the dimples causing some degree of shifting of the air space and reduced drainage capacity, yet the foundation is unharmed. Most foundation walls would buckle under these extreme conditions but the membrane prevents that.

Delta®-MS exterior foundation wrap will perform well in most soils. If the soils contain clay and are expansive, coarse sand can be used as a backfill against the drainage board to broaden the load as a buffer zone, thereby reducing the force of expansion from the soil. You could have a load up to 1200-1800 pounds per square foot and still maintain 90% drainage.

If soils do not drain well Walker suggests you may be better served with the Delta®-Drain system that can handle higher pressures and enhanced drainage capacities. The commercial grades of the Delta®-Drain series (the 2000 and 6000 series) drain up to 18 gallons of free water per minute per foot of width on vertical walls, more than one would see in expansive clay soils.

The U.S. Department of Agriculture has compiled soil surveys for every county in the country. Walker can review the specifics for any building location, once soil data is obtained, to match the right Delta® air gap drainage membrane to the specific soil characteristics of the location of the building lot.

Finally regarding cost, a Delta® drainage membrane is cost-competitive with drain board and saves on labor compared to other waterproofing systems due to quicker installation. It also saves money compared to more expensive washed graded rock as backfill. Finally, drainage membranes keep the entire foundation of the house warmer, saving fuel bills.

12.4 The Physics of Vapor Pressure and Vapor Migration

According to Cosella-Dörken's Dwight Walker, in order for their air gap drainage membrane to keep a basement completely dry, the homeowner must keep the temperatures in the basement or crawl space high enough to prevent outside water vapor from moving inwards through the wall. This happens due to lower vapor pressures inside compared to outside.

As temperature increases, vapor pressure in the air also increases because warmer air can hold more water. Therefore, if indoor air is warmer than air within the gap of a drainage membrane outside the foundation, then basement air and water vapor will be slowly pushed out through the foundation, regardless of the materials used. The warmer the air in the basement, the higher is the pressure pushing vapor from inside to outside. This occurs as long as you keep the basement temperature higher than soil temperatures, usually a constant 55-60 ˚F at approximately six to eight feet below ground. These temperatures would be lower in northern climates in winter the closer you get to the surface.

For example, when the soil temperature is 50 ˚F, the saturated vapor pressure of water (that is, the dew point above which it rains or condenses as free water) is 9.84 millimeters of mercury (mm Hg) within the air space between the dimples of the drainage membrane. The saturation density in the same space, on the other hand, which is the maximum weight of water in air, would be 10.01 g/m^3. By contrast, inside the foundation wall, if the basement air temperature is 68 ˚F (18˚ higher than outside), the vapor pressure will be 17.54 mm Hg (compared to 9.84 mm Hg outside) and the saturation density will be 17.3 g/m^3 of air (compared to 10.01 g/m^3 outside). The values inside the wall are both higher than outside the wall, in the cooler dimple air space. Therefore, liquid water condenses outside the foundation, where you want it to, rather than inside of the basement wall when conventional waterproof coatings and rigid foam board are used.

Some moisture will wick back through the wall via capillary action, but if the basement temperature is warm enough, the moisture will evaporate as soon as it comes into contact with warmer inside air. This avoids condensation inside the basement wall and prevents mold growth.

Using low-density fiber-cement blocks rather than concrete for your foundation is fine with Dwight Walker as long as you keep the basement or crawl space air temperature above 55 ˚F, above outside soil temperatures, just as with a concrete foundation.

12.5 Waterproofing Homes with Hydronic Heating Systems without Forced Air Pressurization

Building biologists recommend in-floor, in-wall or baseboard hydronic (hot water) heating systems rather than a forced air handler. Yet if you install radiant heat without forced air, the house will not have the higher basement air pressures typical with a force air heating and cooling unit. This increased air pressure normally pushes moisture out through the foundation wall when an air gap drainage membrane is installed.

Therefore in homes without a forced air unit the air pressure differential inside the foundation versus outside will be less, resulting in a tendency for more wicking of moisture inwards from the dimple air space. This can be counteracted by:

1. Always keeping the basement or crawl space warmer than the outside soil temperature. This is especially important in the absence of a forced air heating unit.
2. Use low-density fiber-cement forms rather than concrete as your foundation material.

These steps will stop moisture from wicking back through the foundation by capillary action. When low-density fiber-cement is used as a foundation material, what moisture does wick through will evaporate due to the breathable nature of the air spaces within the block.

12.6 Wicking of Moisture from Foundation Footing

On the topic of wicking of moisture up from the footing, Dwight Walker writes the following. (Bear in mind that he is speaking of his company's usual customers who pour a concrete foundation or use concrete block.)

> Other moisture that can migrate into the basement is the result of "wicking" through the capillaries of the concrete footing, which transfers this moisture up into the foundation wall area and into the living space of the basement. *[This will not occur if low-density fiber-cement is used as the foundation wall. – Ed.]* This transfer of water can only be deterred if a capillary-breaking material is placed between the wall and footing interface during the construction phase, or under the base and along the sides of the footing itself.
>
> Our Delta® MS membrane provides an air gap on the exterior face of the foundation wall providing some relief by allowing this "wicking" moisture to migrate to the exterior and drain into the perimeter tile system. Short of this, there is little that can be done economically to stop this entry point of moisture into the living space.
>
> This moisture can and does to a large part cause the problems associated with mold growth in basements, in addition to the lack of detailing of the "underslab" area of the basement where vapor moisture under the concrete floor slab can enter through capillaries and cracks.

See section 11.3 for alternate slab protocols that successfully avoid the very problem Walker is talking about. Again, if low-density fiber-cement forms are used below grade rather than a poured concrete foundation, water will not wick through these materials into the basement the way it does through concrete.

In spite of this it is still wise to proceed with Walker's suggestion to incorporate a capillary break between the footing and the wall. In order to accomplish this he recommended the following:[271]

> The footer will wick up moisture. You need a water stop or capillary break between the footer and foundation wall (a custom job) or, a capillary break in the soil before pouring the footer. Use 6-10 mil stabilized, virgin plastic polyethylene (which may react with the alkaline in concrete and could deteriorate over a long period of time).
>
> It is more common to put the break between the footer and the wall, using neoprene or an asphalt peel and stick. *[This is one application of peel and stick of which we approve. –Ed.]*
>
> Key out the footing so the wall itself does not slide during the back fill to hold the bottom of the wall on the footing, because there is no friction if a capillary break is applied there.

[271] Dwight Walker, personal communication.

See section 17.4 for a protocol for constructing a mold-free basement foundation and stem wall for a crawl space.

12.7 Crawl Space Considerations

In general our profession does not recommend a crawl space for several reasons:

1. The exposed soil is a "mold factory" and is never adequately sealed in real conditions, no matter how carefully one lays and seals plastic sheeting.
2. Attempts to control ventilation often fail to provide sufficient air flow to prevent mold, and mechanical systems that do so are prone to failure. If you do provide sufficient ventilation to avoid mold, you run the risk of producing heat loss.
3. Air ducts that run in crawl spaces pull soil gases and mold spores into the air stream, bringing these unwelcome elements into the living space. They also leak moisture out into the crawl space. This promotes condensation on the inner surfaces of cooler stem walls that may result in mold growth.
4. Rigid foam board used as insulation traps moisture between it and the stem wall.

Instead we prefer either a full basement built according to the protocols given above, which provide a usable, comfortable, dry and mold-free living space, or placing the home on a slab on grade or elevated on a raised plinth.

If you do choose to design a crawl space, we make the following recommendations:

- Provide cross-ventilation in excess of standard guidelines to allow fuller airflow at all times, except in the coldest months of the year. Experienced builders buck the trend of mechanically enclosing crawl spaces. Mold does not grow in moving air. Include provisions to close off this ventilation in the winter months to always maintain a crawl space temperature in excess of soil temperatures, usually 55-60 ˚F.
- Open vents in warmer months, from spring through summer to autumn. Keep the air moving. Install a quiet, low-sone exhaust fan if necessary (powered by a branch circuit using armored cable rather than plastic-jacketed Romex® to avoid exposing residents to electric fields in living spaces above).
- The same holds true in humid climates. The International Institute of Bau-biologie® and Ecology's founder, Helmut Ziehe, always says that mold was not a problem in Florida's crawl spaces until builders closed them up and put in one small vent hole per side. Prior to that they used concrete blocks with open designs to allow wind to pass through, and mold was never a problem. The underside of the home can still be properly insulated to avoid loss of coolness from air-conditioning.

- When the inside soil level is below grade, that is, below the outside soil level, you need waterproofing. We recommend low-density fiber-cement blocks for stem wall foundation construction plus cementitious nontoxic breathable foundation waterproofer and an air gap drainage membrane on the outside to allow water to drain to French tile at the base of the stem wall.
- Use cotton batting rather than fiberglass at rim joists under the first floor to maintain good indoor air quality.
- Around supply and return air ducts, use cotton insulation wrap such as made by Superior Air Duct (713-682-3828; www.superiorairducts.com) rather than fiberglass, for the same reason, that is, to avoid harmful microscopic glass shards from entering the air stream in case the lining of conventional flexible air ducts were to tear.

Rather than covering the soil in the crawl space with heavy-duty plastic and trying to seal at seams and around the periphery, which is bound to fail at some point, we recommend a different protocol. First, prepare a milk-thin mix of 70% bentonite clay, 25% magnesium oxide and 5% borax and water and spray onto all exposed crawl space areas. Then powder the same dry mix about ¼ inch deep onto the leveled earth and lightly hose it with water to bleed into the soil. This semi-hardens the soil, helps control moisture and neutralizes all odors, and most importantly waterproofing can still "breathe." You can also apply this treatment to crawl spaces that have been treated with toxic pesticides to assist in remediation.

One should also provide for proper removal of water with a sealed sump pump in cases of high water table.

We realize that our recommendation to open a crawl space to outside air nine months of the year is contrary to currently accepted building practices, which advocates sealing a crawl space and mechanically conditioning it. Yet there are enough cases of failure with the conventional practice to warrant a rethinking of this approach. We recommend a return to the time-tested method of proper ventilation and adequately managing temperatures in order to prevent mold from growing in the first place. This is particularly true when our recommended approaches are used, which keep mold growth in check by providing adequate airflow and breathability of materials.

To make this work and avoid mold, three rules of thumb should always be followed, according to Dwight Walker:

1. Keep the crawl space air temperature above the temperature of the outside soil
2. Reduce air intake from outside during the winter season to maintain a suitable interior crawl space temperature
3. Keep moisture out of the crawl space by sealing all air ducts with mastic at every seam

This last point is important because the air in the living space upstairs is warm in winter, and that warm air circulates in return ducts running through a cool crawl space. This air is also more humid than dry crawl space air in winter. When it leaks out into the crawl space through gaps in the seams of the ducts, the moisture will condense on the surfaces of the colder stem walls, causing mold.

Therefore we recommend you seal all air duct seams, preferably with a long-lasting sealer such as mastic, rather than duct tape. Likewise seal all holes in the floor between the crawl space and the first floor in order to keep moisture from escaping to the crawl space from above as well as to insulate against heat loss.

Additionally, in hot humid weather, if you use air conditioning, the living space upstairs contains cooler air that circulates through the ducts running in a warm crawl space. Warm, moist air from the crawl space can be pulled into the cooler ducts through gaps in the seams. This moisture condenses on the cool inner surfaces of the ducts, below the dew point of the air. This condensation, of course, causes mold.

Finally, if you use a hydronic heating system and do not have forced air heating you will obviously not have a problem with moist air seeping into the crawl space from upstairs through leaky ductwork, since no ductwork exists from which moisture can escape. Just be sure you don't have any major holes in the floor between the crawl space and the first floor living area that would allow this to happen.

If you only use radiant heat and you seal holes in the floor above the crawl space, the temperature within the crawl space should generally remain equal on both sides of the stem wall and you should not have significant condensation problems.

12.8 Frost-Protected Shallow Foundation

A popular and affordable stem wall[272] alternative is the use of a Frost-Protected Shallow Foundation. This calls for laying rigid thermal insulating board horizontally a few inches underground at right angles to the stem wall, effectively raising the frost line and preventing the soil underneath from reaching colder temperatures. Informative articles on this topic can be found at the Oikos[273] and Toolbase Services[272] websites.

Furthermore, Frost-Protected Shallow Foundations typically utilize polystyrene insulating foam board. The chemicals used in the manufacturing process, ethylbenzene and styrene, can be occupational and environmental hazards for plant workers. Polystyrene is best to be avoided, although the end-product is nontoxic and ozone-depleting blowing agents have been phased out.[274]

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[272] See http://www.toolbase.org/ToolbaseResources/level4DG.aspx?ContentDetailID=501&BucketID=4&CategoryID=5 for an explanation of stem walls.
[273] See http://oikos.com/esb/43/foundations.html.
[274] *[This footnote will be written later. –Ed.]*

Nevertheless, in keeping with the principle of choosing breathable and nontoxic materials over non-breathable ones, we now present George's alternative protocol to the use of rigid insulating board. He claims it is much better to put several inches thick of loose, crushed pieces of low-density fiber-cement wall form a few inches below grade with filter paper on both sides, or if chips go all the way to the surface then filter paper only below for silt protection.

This system will “breathe” and allow water to pass through and disallow frost penetration. No water equals no frost. George has been told this has been done in Europe, in various incarnations, for a long time. The only downside is preventing the barrier from being penetrated by unsuspecting future gardeners!

The argument that the low-density fiber-cement wall form chips have less R-value per inch than extruded polystyrene is countered by the fact that the pieces of wall form stay dry due to air pockets plus gravity drainage. When foam gets damp or wet, as it often will below grade, its “effective” R-value can sink to near zero and at saturation it can become a moisture conductor, not to mention the fact that this creates a perfect mold environment.

Chapter 13. Roof and Attic

13.1 Introduction

Our profession has recommendations for roofing materials and attic design and construction to create a healthy indoor environment, using sustainable design. Once again we follow time-honored traditions that when combined with our breathable slab, foundation and walls provide an environment that allows moisture to dry out and prevents mold. The roof and attic complete the building envelope.

13.2 Attic

The Building Biology® profession teaches that the roof should act as an umbrella over the conditioned living space inside. Old timers in the building profession say you want your attic to be well vented so that when standing in it on a windy day you feel a breeze. The only exception to this would be the deep South, where it is sufficiently humid for enough months of the year that sealing the attic and using mechanical ventilation makes sense. Otherwise, allowing for adequate (but not excessive) ventilation will prevent many problems with mold and structural damage, as this allows moisture to dry within the 24 to 48 hours before mold can grow. If the attic floor is well insulated, energy efficiency is maintained in the living space beneath. Remember, warm air rises, so insulate your attic floor well using a plastic air barrier. This would be the one place that we recommend such a barrier if used in conjunction with a well-vented attic space.

As you add insulation around the perimeter of your attic, be sure to leave regularly spaced air passages at the perimeter and above the soffits for air to circulate. This can be accomplished with plastic air chutes placed in every other cavity between joists, and then insulation can be packed around them.

Even so, along the perimeter of your attic you still end up with less insulation because the slope of the roof just does not allow enough room for the same loft as you have elsewhere in the attic. Many builders solve this by providing what they call an “energy heel” in their wall design to accommodate this. The vertical wall continues up another couple of feet above the floor of the attic and then the pitched roof begins. That way the full loft of insulation can extend all the way to the perimeter, where you still maintain your air chutes to your soffits.

When you do install batt or blown-in insulation in your attic, be aware that when it is walked upon, it never regains its original loft. We discussed this in chapter 7. This is confirmed by thermographic imaging showing heat loss through the ceiling of the room beneath. For that reason, many builders recommend first laying batts of insulation, preferably cotton, followed by blown-in loose-fill cellulose above that. Cotton batts spring back and retain their loft better when walked on than fiberglass or blown-in insulation.

Cathedral ceilings are popular these days and present their own challenges. Modern technique completely fills the cavity between roof decking and the drywall of the ceiling beneath with rigid foam or batt insulation, leaving no room for air to circulate. Architects and mold experts recommend providing an air gap along the underside of the roof decking *above* whatever insulation you use. This should provide a continuous air passage from the soffit to the roof peak, where a ridge vent should be installed. This is discussed in detail in chapter 7 on Water Intrusion.

Several strategies are mentioned in section 14.8 to efficiently cool an attic space. These include solar-powered attic fans and the use of a product called Radiosity® (www.radiosity.biz) made up of tiny silica beads that are mixed into paint and brushed or sprayed onto the underside of roof decking. This is known to reduce summertime attic temperatures from 170° down to 140° F.

Other cooling strategies include choosing light-colored tile or asphalt shingles (which we do not recommend) rather than darker colors, in order to reflect rather than absorb hot summer sunlight. Skylights and monitors provide natural cooling in summer through what is known as a "whole-house chimney effect." Skylights will penetrate attic space and must be flashed and caulked properly at the roof line to prevent rainwater leakage. Solar tubes, which are an excellent way to provide daylighting to interior living spaces, reducing electricity usage and preventing seasonal affective disorder (SAD) in winter, will likewise penetrate attic space and must also be flashed and caulked properly at the roof line.

Roof pitches should take into account the proper alignment to the sun to accommodate solar thermal panels for hot water heating as well as photovoltaic panels to generate electricity. Either install these energy-saving devices when you build your home or provide the infrastructure so that your house is "solar ready" and you can add these features later when finances allow. While it may take almost two decades with current PV technology for full payback of the installation costs for solar electric panels, you do reduce your carbon footprint immediately. PV panels come as stand alone panels or they can be incorporated right into roofing shingles.

In warmer climates, heating, ventilation and air conditioning (HVAC) equipment is often placed in an attic, especially because many homes do not have basements in the South or Southwest. First of all, be sure that a well-sized and maintained pan is located under equipment to catch the inevitable water leak or dripping from condensation that will occur from this equipment. Second, the ducts need to be well-insulated to prevent energy loss during cooling season as well as to avoid condensation within the ducts. Superior Air Ducts (713-682-3828; www.superiorairducts.com) in Houston makes cotton-filled duct insulation wrap for metal ducts, which we recommend. They also make a cotton-lined semi-flexible air duct that is the only non-rigid duct material we recommend. See chapter 14.

Third, we recommend sealing all air duct seams with mastic, not duct tape, to prevent moisture-laden attic air from entering the air-conditioned air stream and condensing on the inside of ducts, causing mold. Mold experts claim that sheet metal is the one material that mold will not grow on, but it seems nothing stops Mother Nature from doing what she wants when the conditions are right. Builders in the south claim they have in fact seen mold growth even on sheet metal in air ducts. The solution is not to treat it with a fungicide, but rather to prevent the conditions for its growth in the first place.

13.3 Roofing

Building biologists say that the best roofing material is slate, as it is the least toxic and most environmentally friendly. Also recommended are clay tile, masonry and cement tiles. Metal has advantages but it blocks helpful cosmic radiation. Voss Tile is another good product for roofing. It is two to three times more durable than asphalt. The tiles last over 100 years. They are excellent for rainwater catchment. Contact Voss Tile & Stone (P.O. Box 317, Anacortes, WA 98221; 360-293-0608).

Asphalt shingles, the roofing material of choice throughout America, need to be replaced as often as every twenty years and are not a wise choice environmentally or economically.

Synthetic roofing material made from recycled tires is now popular on the market because it is considered a "green" product. Questions arise, however, in the minds of some developers as to whether it is made in an environmentally safe way and whether there is an outgassing potential. George suspects that the production of the material is most likely in an unhealthy environment for the factory workers just as it is not so good for the installers (especially on a hot day). Secondly, the occupants could suffer from long-term outgassing of the material through the conventional materials used in a cathedral roof. Another reservation is that water collection from the roof will never be possible. Also plants at the edge of the building will be permanently negatively affected by the roof and downspout runoff.

Roof decking should consist of one of the magnesia-based sheeting products listed in section 8.11 rather than oriented strand board (OSB) or plywood. OSB delaminates when it becomes wet and moldy. MgO sheets, on the other hand, dry out when wet and retain their structural integrity. They are also strong enough to resist damage when roof tiles are dropped on them.

Building biologists also recommend you generally avoid flat roofs, as they pool water. (Green roofs are an exception to this – see below.) An alternative for flat or low-slope roofs is the one piece, white, thermoplastic membrane roof produced by Duro-Last (www.duro-last.com; 800-242-0280). Usually used in commercial and industrial applications, the system is also available for residential applications. The roof is prefabricated at the factory, including all penetrations, and it eliminates rainwater infiltration by reducing possibilities for leaks during onsite construction. Seams are therefore much tighter. All workmanship and protection against rainwater intrusion is checked upon completion.

So-called "green" roofs are a great addition to a home or business, provided they are well designed and maintained, and most importantly, well installed so that water leaks do not develop. A green roof is a flat or slightly sloped assembly of live native plants that provide significant cooling to the building in summer. Obviously you want to be sure your roof is installed properly and that leaks are attended to immediately and correctly. It is said by mold experts that ninety percent of moldy basements can be avoided by proper rooftop rainwater management, so a well designed, installed and maintained roof is essential to avoid mold. Gutters need to be installed unless you have large overhangs all the way around. Those gutters need to be well maintained with gutter guards and/or cleaned regularly to avoid accumulation of debris from nearby trees. Otherwise you will see streaking of a brownish stain on the edge of your gutter, indicating water is spilling over the edge in a heavy rainstorm and landing near the foundation. Another telltale sign is pitting of the ground in a row directly under the gutter. Notice how close to the foundation this puts a heavy accumulation of rainwater. Finally, make sure downspouts are in good working order and that they drain to extenders that carry the water well away from the foundation.

Incorrectly installed flashing underneath the gutters can cause rainwater to seep between the gutter and the edge of the roof, again causing a row of pitting of the ground directly beneath, depositing even more rainwater close to the foundation. The best thing to do is to go outside in your raingear during a heavy storm and see where rainwater is going. Are there any places the water is pooling next to the foundation?

Roof overhangs are beneficial as a part of passive solar design. They also provide weather protection for siding and walls.

Finally, ice dams are a problem in northern climates, causing mold when melting snow refreezes as it hits the cold roof overhang, penetrating under shingles and dripping onto attic insulation underneath, causing mold. To remedy this, apply ice and water shielding under the lower six feet of roofing material to avoid ice dams if asphalt shingles are used. Also take steps to keep warm air from escaping into your attic from the living space below, which would thereby melt rooftop snow and cause ice dams in the first place. Seal the attic hatch with weather stripping, glue cotton batting insulation on the top of the hatch, and seal up any penetrations, such as around chimneys or vent stacks, where warm air can escape into the attic.

It is especially imperative that you not allow bathroom or kitchen fans to vent directly into the attic, thereby putting warm, moist air where it does not belong and causing mold and ice dams. Instead, be sure that bathroom and kitchen fans are vented to the outside.

Chapter 14. Additional Design Considerations

14.1 Introduction

Now that we've surrounded ourselves with a thick, breathable envelope, we put forth some additional design considerations that are necessary for the envelope to function optimally: moisture control, ventilation, passive solar design, windows and doors, and provisions for heating and cooling.

14.2 Moisture Control (Adjunctive to Breathable Envelope Materials)

Now that you have a better understanding of how breathable envelope materials keep your walls and foundations dry and mold-free, there are further steps you must take to keep them that way and to create healthy indoor air quality in your home and office.

As explained at length in chapter 7, moisture control is your number one defense against mold. Rather than eliminating moisture exclusively through sealing and mechanical ventilation strategies that often fail in the real world, consider the words of a successful high-end renovation expert in Minneapolis, Shesh Andahl of Andahl construction. She is fond of saying, "Mother Nature always wins." She realizes that remodeling a home with moldy walls requires you to allow for drying of the inevitable moisture infiltration. Add to that the words, already quoted, of University of Minnesota Industrial Hygienist Neil Carlson, that, "All buildings will have a water event at some time in their life." To effectively counteract these influences and successfully manage mold and moisture, Building Biology® and a growing number of forward-thinking individuals in the building industry, recommend the following steps. This summary includes information already discussed plus new steps to assist in keeping buildings dry:

- Provide adequate runoff for rooftop rainwater. This takes care of 90% of mold problems in basements and should be one of the first considerations in keeping the foundation dry. Therefore keep rain gutters clear of debris and downspouts in good working order. Make sure downspouts have extenders that drain at least several feet away from the foundation. Reattach them after you (or the kid next door) mow the lawn. If you have an underground drainage system that runs to daylight, make sure the drain pipe remains open—they often close over with dirt and grass. We do not recommend an underground drain field as these fail over the decades.
- Don't let a sprinkler spray directly against the side of the house. Avoid "power-washing" your house. Oram has seen this cause mold in walls.
- Keep flowerbeds and shrubs a few feet away from the house if you water them regularly.

- Provide a breathable foundation and above-grade walls that dry out when they become wet, the most important thing you can do to prevent mold caused by condensation on walls.
- Install a perimeter drainage system at the base of your foundation to drain water to daylight or to an exterior sump pump. Locate this below the level of the slab to avoid entry of water that may collect if the drainage system becomes backed-up. Likewise keep it above the bottom of the footing so backed up water does not undermine the footing.
- Use a nontoxic, breathable waterproofer as well as an exterior foundation wrap (air-gap drainage membrane), as discussed above in chapter 12. This harmlessly drains water to your perimeter footage drainage system. This combination keeps your foundation warm and reduces soil translational pressures.
- Slope or “berm” the earth away from the house approximately five to ten degrees to ensure that rainwater runs away from the foundation.
- Place broken-up pieces of cement-bonded wood fiber wall form under the concrete slab, as a breathable, insulating thermal and capillary break, as discussed above in chapter 11. Avoid rigid foam board under slab, a frequent cause of mold. GreenKrete Building Systems states their poured-in-place fiber-cement slabs make this step unnecessary, as the slab contains no concrete.
- In the winter, keep the temperature of the basement or crawl space air warmer than the temperature of the soil on the other side of the foundation or the crawl space stem wall, usually 55-60 ˚F. This avoids condensation from forming on the inside of foundation or stem walls. Do this by locating heating equipment in the basement or crawl space.
- Likewise, air ducts in a crawl space or cold basement must be tightly sealed, preferably with mastic, to avoid moist indoor air from leaking out and condensing on basement or crawl space walls.
- Also do a good job of insulating any air ducts that run in your attic to avoid condensation and mold from forming inside the ducts during hot summer days.
- In warmer weather, when outdoor humidity is not excessive, increase ventilation of your basement and crawl space air to the outdoors. While controversial and contrary to current practice, many experienced builders find this approach to be the best. When combined with the other practices recommended in this manual, this can be a successful strategy.
- Properly apply flashing around window and doorframes to keep rainwater out of wall spaces. This is critical for maintaining a mold-free wall, particularly in conventional wood-frame construction.
- While we recommend radiant heating and cooling systems, if you do install a forced-air system, provide low-flow air circulation throughout the house to help suppress mold and mildew. Depending upon your climate, when you employ the whole house natural cooling strategies we recommend, you may only need a wall-mounted air conditioner or lower-btu A/C system with minimal ductwork.

- Install low-noise (low sone) bathroom and kitchen exhaust fans, vented to the roof or to a soffit (but *not* to the attic). This reduces excess indoor moisture. Add a timer to the bathroom fan switch to allow moisture to exhaust for up to twenty minutes after you shower and leave the bathroom. The vent to the roof should have a flapper valve to keep cold air from entering. Be sure you provide sufficient fresh air makeup for combustion appliances so you do not have backdrafting of exhaust gases from a gas-fired hot water heater (sealed combustion units are preferable, or better yet, install an on-demand hot water heater).
- Use pervious cement for driveways, sidewalks and carports to allow percolation of rain water through what would otherwise be an imperious, paved surface. This is particularly necessary in dry climates where aquifers need to be recharged.[275]

14.3 Ventilation

To provide a comfortable living environment, buildings must provide adequate ventilation, at least 30 cubic feet per minute per person according to the standards of the Institut für Baubiologie und Ökologie Neubeuern (IBN) in Germany. Building scientists like to refer to the number of complete air exchanges per hour (ACH) between inside and outside. The Building Biology® standard converts to 0.1 ACH per person in a "typical" 2200 sq. ft. home. It is not commonly recognized that the required ACH varies, directly in proportional to the size of the building. A larger, 3300 sq. ft. home needs 0.15 ACH per person. For four persons these values translate to 0.4 or 0.6 ACH, respectively.

Ventilation can be provided by either natural or mechanical means. Vapor barriers, which prevent any "natural ventilation" through walls, and mechanical ventilation are the norm in modern, superinsulated construction. As building biologists we prefer natural ventilation, including through our walls, while maintaining good thermal performance. As we discussed in chapter 6, our breathable walls do permit a small amount of diffusion of fresh air, however experts in our profession believe that this air exchange occurs at a rate sufficient to provide no more than a small amount of fresh air to the interior space.

That leaves several options to promote natural ventilation. These include:

- Installing cupolas and skylights with humidistat-controlled motors to automatically close skylights when rain approaches. George recommends "cool tower" cupolas on his jobs in Texas.
- Install whole-house fans along with cupolas and skylights can provide a chimney effect, flushing warm air up and out at night and drawing in cooler night air through open windows.
- Construct vented attics, preferably with solar-powered attic fans. Old-timers say you should feel a breeze on a windy day when standing in your attic.

[275] We recommend you visit EcoCreteo USA, Inc. at www.ecocreto.com.

- Open windows or preferably, install trickle ventilators into window casings (www.titon.com).
- Make use of the stack effect (which can also draw in soil gases, including radon).
- Cross-ventilation can be provided by clear sight lines between windows on either side of the home.

Strategies to reduce the need for large, mechanical whole-house air-conditioning and forced-air ventilation systems include:

- Designing overhangs on south sloping roofs or awnings and trellises over southern windows to shade south walls in summer.
- Fewer and smaller low-E windows in the west wall to reduce the sun's penetration into the home on late summer afternoons.
- Landscaping with deciduous trees to the west to shade the house in summer and allow warming sunlight to pass through in winter.

All of these strategies work the best when the envelope is built with one of the breathable, thick-wall materials recommended in this manual. Even the thin-wall protocol put forth by George Swanson using MgO boards and cotton insulation is breathable and has some degree of thermal mass. Using that protocol will also help these strategies be more successful. With careful attention to site selection and building design, in the most favorable conditions it is possible to ventilate solely by natural means. When additional mechanical ventilation is needed, the size of the forced-air system can be substantially smaller when breathable, thermally massive envelopes are built and these strategies are followed. We do agree with many building science experts today that an air-to-air heat recovery ventilator (HRV) or energy recovery ventilator (ERV) would be a worthwhile investment when mechanical ventilation is desired, but these can be designed into a small-scale or wall-mounted system.

An important point to remember regarding air exchange is that the average exchange per hour through doors and windows alone of a new, "tight" home is around 0.5, or half of one room exchange per hour. Some super-tight homes go down to 0.2 room exchanges per hour. This can be supplemented, of course, by mechanical air exchangers, but there are a few down sides to using that as your exclusive source of fresh air intake. They include the depletion of healthy negative ions by traveling through metal ducts (creating a less healthy positive electrostatic charge), the potential carrying of mold spores, and the system's vulnerability to power failure and improper owner maintenance and operation.

To that end, there is a range of opinions among building biologists whether or not mechanical ventilation is appropriate or necessary. The University of Waterloo's John Straube writes[276] that "Ventilation is always necessary because it aids in the

[276] V. Acharya and J. F. Straube., "Indoor air quality, healthy buildings and breathing walls," in the *Proceedings of 1998 Excellence in Building Conference*, Washington D.C. The manuscript was posted at http://oikos.com/library/breathingwalls. A slightly enhanced version by J. F. Straube and J.P. deGraauw was published under the title "Indoor Air Quality and Hygroscopically Active Materials" in the *ASHRAE Transactions, volume 107, part 1* (2001).

removal of other pollutants and delivers oxygen to a room faster than diffusion." However, he also says that "Ventilation … cannot always guarantee moisture removal in the corners of rooms, behind furniture, etc." And, as previously quoted in chapter 8, he states in the same paper that

> Hygroscopic, "breathable" walls operate automatically, require no energy and cannot break down (that is, mechanically fail as ventilation equipment does). Such walls can also react much more quickly than ventilation. Ventilation and breathing walls are likely best used as complementary techniques for ensuring IAQ [indoor air quality].

Much depends upon the climate in which you live and your family's personal preferences. If one designs for mechanical ventilation, it would be wise to use short and straight metal airways and slow flow rates if possible. This minimizes the problems associated with ductwork (electrostatic charging that depletes negative ions; growth and spread of dust and mold; difficulty in cleaning—however do see our recommendation below of a semi-rigid, cleanable flexible air duct from Superior Air Ducts in Houston). Small bathroom and kitchen fans are a first step (provided they do not cause backdrafting of hot water heaters), although they do not provide any heat exchange. They must be vented to the outside, not to the attic. Soil heat exchangers are commonly used in Europe and may fulfill the above criteria. In any case, one does need to provide at least the air exchange rate mandated by the Building Biology® standard. In spite of their drawbacks, HRVs and ERVs do help to provide this.

One point regarding the amount of air exchanged through a low- density cement-bonded wood fiber wall, even though it is estimated at only a few hundredths of a room exchange per hour, is the following. Even though the core of the wall form consists primarily of concrete, which is not considered a breathable material, at least one quarter to one third of the total wall surface is fully continuous cement-bonded wood fiber material straight through. This accounts for the small degree of air exchange you do have with such a wall system. George points out that what fresh air does enter the wall moves at approximately one inch per hour. As cold winter air reaches the inner one third of the block, he says 70-90% of the thermal gradient between the outside and indoor air disappears. Thus thermal performance is not lost. Contrast that with modern fiberglass batt-insulated walls where rapid air infiltration can bring cold air close to the inner surface of the wall.

George highlights the importance of cement-bonded wall forms and air exchange by stating that all the "breathing" in the Durisol or Faswall system is, of course, through the block ends and "fins" that create the divisions within the block. This area is generally about 25-30% of the total face area of the assembled wall. He goes on to say, naturally the amount of "breathing" through the wall is changing from minute to minute as both indoor and outdoor pressure and humidity are changing during the day, so the room exchanges per hour are simply representative of a much more complex variable. This would also change from climate zone to climate zone. If pressure and humidity are identical (rare situation) on both sides of the wall, naturally the movement of moisture and air is less.

George goes on to point out that while the amount of air diffusion through one of his breathable, low density walls is small, it is enough to take care of vapor diffusion and the maintaining of a mold-free environment within the block itself. This is admittedly hard to measure as the pressure and humidity on each side of the wall constantly changes from season to season and hour to hour as the sun tracks the building. Nevertheless, this is an important factor influencing the longevity and health of the building, not to mention its occupants. Walls that self-regulate their humidity are valuable indeed.

14.4 Passive Solar

Passive and active solar design both make use of free energy provided by the sun. When incorporated into the initial design of homes built with thermally massive walls, significant savings in life-cycle costs can result. Consider the following:

- Include roof overhangs, awnings or trellises and the planting of shade trees around your home. Roof overhangs allow low-angle winter sun to enter southern windows, bringing direct solar gain and radiant warmth to the living space while shading high angle summer sun off these southern windows and walls. This keeps the whole house cooler in summer.
- Install smaller and fewer west-facing low-E windows, possibly with mini blinds between panes. It is these west-facing windows that absorb the most heat from the summer sun. Roof overhangs will not protect against hot solar rays from the west since they come in lower in the late afternoon sky as the sun begins to set.
- Choose medium sized south-facing windows – you want radiant heat and light from southern sun in winter counterbalanced by the desire to avoid the vitality-draining influence from southern and western sun, according to certain ancient Indian principles. Choose larger, east-facing windows as the sun from the east is noted to be more energizing and the rays from the morning sun are considered nourishing.
- Install in-floor tile or colored concrete under south-facing windows to release radiant heat in the late afternoon and evening that is captured during the day from the winter sun.

14.5 Windows and Doors

One of the prerequisites for ensuring high thermal performance when building with thick-wall materials is the choice of windows and doors. A wall with thermal mass has to incorporate good windows and doors in order to properly insulate against outside cold and heat. Therefore generally we agree with builders today and recommend using the highest quality airtight windows and doors possible in conjunction with a thick wall.

Choose low-emissivity (low-E) windows in the west wall because they reflect long-wave radiant heat from the hot summer sun. They also serve to block the exit of long wave radiant heat waves from within the building (if radiant heat is used), slowing the loss of heat to the outside through windows on cold winter days and nights.

Section 9.6 discusses the importance of placing windows near the exterior of the window aperture when using thick wall forms, to avoid moisture from entering the wall and staining inside wall surfaces.

Of course, well-placed windows, skylights, clerestories and solar tubes bring daylight into inner living spaces, decreasing the use of electricity and increasing mood and well-being.

Finally, the choice of window frames makes an important difference in thermal performance and cold air infusion in cold climates. Window frames made with modern materials, including aluminum and vinyl, tend to substantially swell and shrink with variations in temperature, causing your caulk to crack and fail. This allows water to enter the wall cavity. Frames made with fiberglass, on the other hand, swell or shrink much less in response to temperature differences. For that reason we recommend using fiberglass windows of good quality whenever possible.

14.6 Heating

You may have already read about radiant heat transfer involving the building envelope in section 6.7. There we provide you with a primer on the fundamentals of heat transfer, how the human body responds to heat, and what determines thermal comfort. Designing a good building envelope is arguably the most important step in the quest for thermal comfort, particularly if you choose thermally massive materials. This section will focus on the options for supplemental heating, which is necessary unless you live in an extremely temperate climate or you build a “zero-energy” or “passive” house.

When it comes to choosing what *system* you will use to heat and cool your home, building biologists favor radiant heat over convection (forced-air) heat primarily because it is more in keeping with the body’s own mechanism for naturally heating and cooling itself than a forced-air system. We recommend you couple your choice of heating system with strategies for your entire house to contain and radiate that heat in a healthy way and make full use of the abundant free radiant energy provided directly by the sun.

Forced-air heating and cooling is widely used in this country because of its relatively low installation cost. Yet the money that homeowners save up front is more than exceeded by rising fuel costs, particularly when you don’t choose to incorporate active and passive solar features into your home’s design. Another, hidden cost of forced-air heating is out-of-pocket health care expenses for such ailments as asthma and respiratory illnesses, generally not as common when radiant heat and cool systems are used. One of the best reasons for not choosing forced-air systems is that radiant heat and cool simply feels more comfortable for reasons explained below.

Natural cooling strategies are equally feasible for hot summer months when you use the right approach. This includes proper home design that stores coolness in thick wall materials, that shades the south side of the building with adequate roof overhangs, and that provides cross-ventilation and a whole-house chimney effect. We discuss this in more detail below.

Providing radiant heat and cool is not limited to the use of mechanical systems. According to the educational resource healthyheating.com, "Radiant does not necessarily mean an electrical and mechanical solution. Radiant based solutions can also mean architectural considerations in building envelope efficiency."[277]

Examples of radiant heat sources therefore include a number of approaches:

- Winter sunlight entering through south-facing windows under roof overhangs or awnings.
- Hydronic heating systems such as in-floor or in-wall tubing and cast iron baseboard radiators. (We also recommend hot water copper-tube baseboard radiators.)
- Heating and cooling tubing or wall "mats" can be embedded in plaster or behind wallboard using microtubules. These carry hot or cool water and can also be embedded in the ceiling.

Figure 47. Hydronic tubing to be embedded in plaster. (Photo courtesy of Green-Krete Building Systems.)

- Wood-burning stoves are acceptable provided they are well sealed and properly used so as to not add particulates to indoor air. Corn and wood pellets are an alternative fuel to firewood.
- Traditionally the best form of radiant heat was provided by a masonry heater, known in Germany as a "Kachelofen" or "Grundofen." This is a large metal radiant heater covered by ceramic tiles, fired by wood or

[277] See http://healthyheating.com/about.htm. This organization offers "free fact based education on health, wellness and comfort using radiant based HVAC systems as a solution to indoor environmental complaints."

> natural gas. They are still used today and are built into the center of a house, radiating heat into all surrounding rooms.

Cast iron baseboard radiators require temperatures much hotter than rooftop solar thermal collectors can generate, upwards of 180 ºF. Rooftop solar collectors only reach temperatures of 120 ºFin winter. Natural gas would be needed as the backup or primary fuel (depending upon the number of collectors installed), but the water to be heated would start at close to 120 ºF, a definite energy savings. Thin-walled copper baseboard tubing with aluminum heat fins are a better match for rooftop solar thermal collectors, as they need only 120 ºF to operate.

The most practical way to use radiant heat in this country, as far as we are concerned, would be a hydronic in-floor or in-wall heating system warmed by solar thermal panels on the roof of a house built with thermally massive walls. This would be supplemented by the storing of sunlight in stone or ceramic tiles laid under south-facing windows. A geothermal system would also be installed to efficiently use the constant temperatures deep within the ground, below the frost line.

What is wrong with forced-air heating in a thermally massive house? Let us start with a quote from *Home Energy* magazine:

> Forced air heat, which merely blows warm air around, isn't as effective in a high-mass house as radiant heat, which physically radiates warmth to people. Radiant floor heating warms the feet, the person, and eventually the adobe. It may take longer to get the walls warm, but once they are warm, they stay that way.[278]

Forced air has the following disadvantages:

- Heats the skin only superficially
- Large temperature gradients, in both horizontal and vertical directions
- Drafty (High turbulence is more uncomfortable, even with the same heat loss.)
- Depletes beneficial, healthy negative ions in room air
- Spreads dust and mold

In "Advantages of Radiant Heat," a concise article in *Fine Homebuilding,* June-July 1992, by Dr. Richard Watson, chairman of the ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers) Radiant Heating and Cooling Technical Committee[279] we find the following:

> Forced-air and baseboard (whether electric or hot-water) heating systems are convective systems because they use air as the primary heat-transfer medium.

[278] See http://www.homeenergy.org/archive/hem.dis.anl.gov/eehem/99/990514.html.
[279] The article is reprinted at http://www.radiantec.com/why/technical-explanation.php.

> Typically, heating outlets or baseboards are placed on outside walls, and the system is designed to fill the area with warm air until the preset temperature on the thermostat is reached. The warm air rises to the ceiling until it cools, falling to the floor for return to the furnace or to fill the convective vacuum created by a baseboard heater. Air stratification and heat loss to the ceiling are significant with convective heat.

The website healthyheating.com also contains an excellent presentation which we highly recommend on indoor environmental quality and human physiology.[280]

Figure 48 shows how gradients in the air temperature affect the comfort level of building occupants. Note that only six per cent of people are made uncomfortable by an air temperature difference from floor to head level of between 5 and 6 °F but the discomfort level rises steeply (the y-axis is logarithmic) when the difference becomes larger. Convection systems are typically characterized by large thermal gradients.

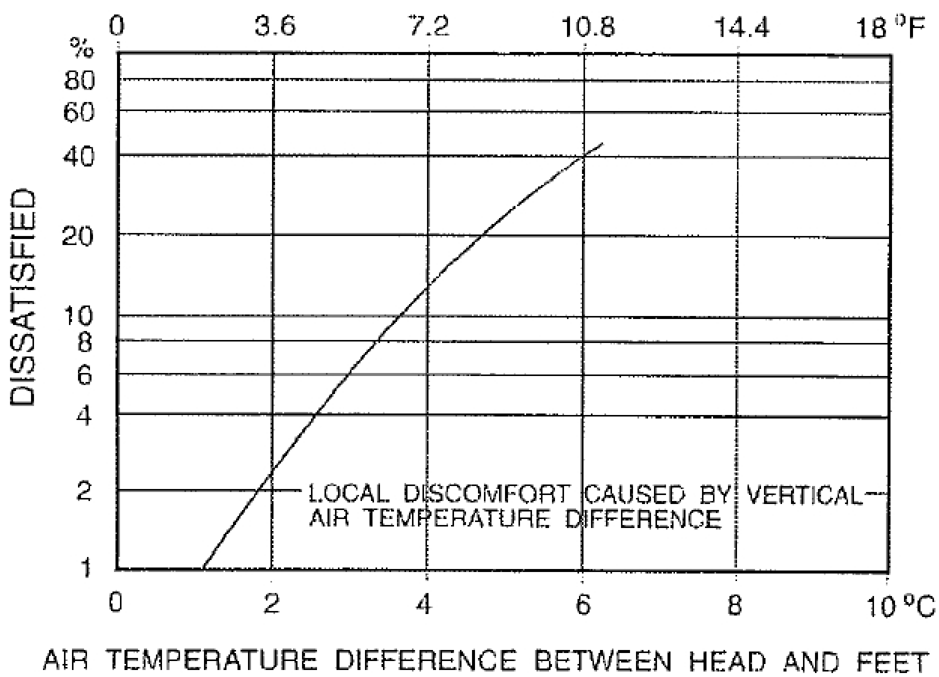

Figure 48. Human focus groups were surveyed for people's subjective comfort level when exposed to head-to-toe thermal gradients of different magnitudes. (Reproduced by permission from ANSI/ASHRAE Standard 55-2004, Thermal Environmental Conditions for Human Occupancy, ©American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., www.ashrae.org.)

[280] The presentation begins at http://www.healthyheating.com/Thermal_Comfort_Working_Copy/HH_physiology_intro.htm.

How does radiant heat overcome these disadvantages? From the Watson article:[279]

> Air is transparent to the transfer of radiant energy, which occurs directly from warmer to cooler objects. With radiant ceiling heat, the temperature varies only about 2 °F to 4 °F between the ceiling and the floor, with the floor being about 2 °F warmer than the air. And radiant floor heating results in reverse stratification. [However, for reasons to be explained below, we favor radiant *wall* heat over either floor or ceiling heat.]
>
> Humidification is unnecessary with a radiant system because radiant heat does not alter residential air moisture content, which is generally adequate if the air isn't dried out by combustion or by increased infiltration of cold, dry outside air.
>
> Another very important advantage of radiant heat is that it does not create what is known as air-infiltration heat loss. This is common with convection heat because when air heated by a furnace comes in contact with a cold outside wall, where supply air vents or baseboard heaters are usually located, the warmer air creates a "stack effect," drawing colder air into the wall from outside through holes and defects.
>
> Watson states that "With radiant systems, the air is only warmed to the temperature of the thermostat setting (which is usually lower to start with), so the temperature differential at the outside wall is less, thereby reducing air infiltration."[279]

One of the most important benefits of using radiant heat is an estimated 25% to 35% lower heat load in a thermally massive house. This is critical these days in our effort to reduce building-related energy use. Remember that buildings consume almost half of the world's total fossil fuel allotment. The Watson article summarizes this as follows:

When applied to the sizing of a radiant system, conventional heat-loss analysis often includes a reduction in design temperature from 70 °F to 65 °F and a 10% to 25% reduction in building air infiltration, exfiltration, stratification and glass heat loss. The average 65 °F radiant comfort temperature with 59 °F day/night setback *should reduce building heat load by 25% to 35% over convective systems*. [emphasis added]

Overall radiant heat is:

- Cleaner (no air turbulence, dirt, dust, pollen, mold, odors)
- Quieter
- More maintenance free and long-lasting than forced air
- Easily accommodates multiple zones
- Does not affect indoor humidity levels so no drying of air

- Has no thermal gradients and is therefore less drafty, and is more comfortable, because the heat travels directly to you so you can have a lower air temperature

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and other organizations design heating and cooling systems around the comfort of occupants. This results in more energy-efficient, comfortable and healthy systems. Their guiding principle is, "Heat people, not air." Studies by ASHRAE have shown that "people can be comfortable at temperatures 6 °F to 8 °F lower than with convective systems."[279]

The best determinant of how comfortable you can be with radiant heat is something known as the mean radiant temperature, or mrt. It is defined by architect and passive solar expert Edward Mazria as "the average temperature of all surrounding surfaces."[281] The mrt of a space is considered to be the most important factor determining how comfortable a person feels in indoor space. This assumes humidity and air movement is normal. The strategy is therefore to keep the mean radiant temperature high and reduce air temperature.[282]

As mentioned in section 6.7, Edward Mazria explains in his book, *The Passive Solar Energy Book*,

> A mean radiant temperature of 75 °F and air temperature of 63 °F will produce the same feeling of comfort as a 70 °F mrt and 70 °F air temperature…Many people feel cooler air is more invigorating, fresher and less stuffy, and that their ability to work and think increases in a space where they are warm but the air temperature is lower than 70 °F.[281]

However the mean radiant temperature, though useful, is only a crude instrument for assessing the interaction of every individual's human physiology with the indoor environment. Another extremely important variable, of which there seems to be far more awareness in parts of Europe and Scandinavia, determines the *design* of an optimal radiant heating system. A team of Russian building scientists at TSENEF, the Center for Energy Efficiency, a non-profit, non-governmental organization in Moscow, and one forward-thinking American scientist at the Natural Resources Defense Council wrote the following in a 1994 publication:[283]

> Another parameter describing indoor microclimate is local *radiant temperature asymmetry*, defined as the difference in radiant temperatures between two opposite-looking surfaces of an object located at any point of the indoor space. An asymmetry requirement imposes a limitation on radiant heat exchange intensity near warm or cold envelope surfaces.
> …

281 Edward Mazria, *The Passive Solar Energy Book*, Rodale Press, Emmaus, PA, 1979, pp. 64-65.
282 This was explained on a web page, http://www.meanradianttemperature.com/index.htm, last accessed November 2007 but no longer available.
283 Yu. Matrosov, I. Butovsky, D. Goldstein, "A New Concept of Thermal Performance Standardization of Buildings," Energy Efficiency, Q. Bull., CENEf, 1 (5) (Oct.-Dec.) (1994); available online at http://www.cenef.ru/home-pg/hp-40e.htm.

> ISO and some Western standards take account of human physiology and present optimum standard values of the average resultant temperature and the radiant temperature asymmetry for living quarters. The ISO Standard, for example, recommends an optimum average resultant temperature between 20 and 21 °C, and a minimum permissible value of 18 °C; the radiant temperature asymmetry should not exceed 5 ºC. In some national standards this upper limit is raised to 7 °C.
>
> The availability of comfortable conditions in the center of room is insufficient for assuring the provision of adequate comfort level in its entire working space (extending as far from the room center as 0.5 m from inner wall surfaces). Therefore, the radiant temperature asymmetry has been also calculated for these rooms. In all cases this temperature asymmetry varies from 9.5 to 11.5 °C at the level of a human head 0.5 m from an exterior wall with a window. Substituting triple for double glazing can reduce the temperature asymmetry by 3 °C, but the comfort requirement will not be met all the same. In the new Dt proposals which effectively require enhanced thermal insulation this comfort requirement is satisfied.

Generally speaking, for a given set of climatic conditions (temperature, humidity, wind, and pressure) we are more comfortable when the radiant temperature asymmetry is small. However our perception of thermal comfort is expressed in terms of the interaction of our sensory organs with the environment, and as it turns out some parts of the human body are far more “thermally aware” than are others. Therefore the *directionality* of any existing thermal gradients relative to the orientation of our body actually makes a great deal of difference in how we feel. Smart design of radiant heating systems factors in these geometric considerations.

Figure 49 plots the subjective comfort level reported by people in a laboratory setting as a function of the magnitude of the radiant temperature asymmetry for each of four different heating configurations. In these experiments, which are reported in the ASHRAE Standard number 55-2004, Thermal Environmental Conditions for Human Occupancy (ANSI Approved), radiant heat or cold[284] could be applied from any chosen direction—either vertically, from floor or ceiling, or horizontally, such as from a wall. Separate plots are shown for each of the experimental configurations and there are dramatic differences in the results:

1. Warm ceilings caused by far the greatest level of discomfort, i.e. some people reported dissatisfaction at a temperature asymmetry as low as 3 ºF, and at least ten percent of subjects reported discomfort with the ceiling heat before anyone complained in the corresponding trials done with other heating geometries.

[284] We realize that, strictly speaking, one cannot apply radiant cold, but it is hard to succinctly express what was actually done so the following clarification is needed for those readers who require precise language: The floor, ceiling or wall could be made cold, functioning as a radiant absorber rather than an emitter of infrared heat. So under these circumstances the person rather than the environment does the radiating.

2. Cool walls caused the second highest level of discomfort, all other factors being equal.
3. Cool ceilings caused relatively little discomfort, i.e. there is something to the phrase "cool-headed."
4. By far the most comfortable mode of radiant heating in these experiments was wall heating, for which the curve rises less steeply than the others. Even with the highest experimental temperature gradient of about 57 ºF, only eight percent of subjects reported discomfort.

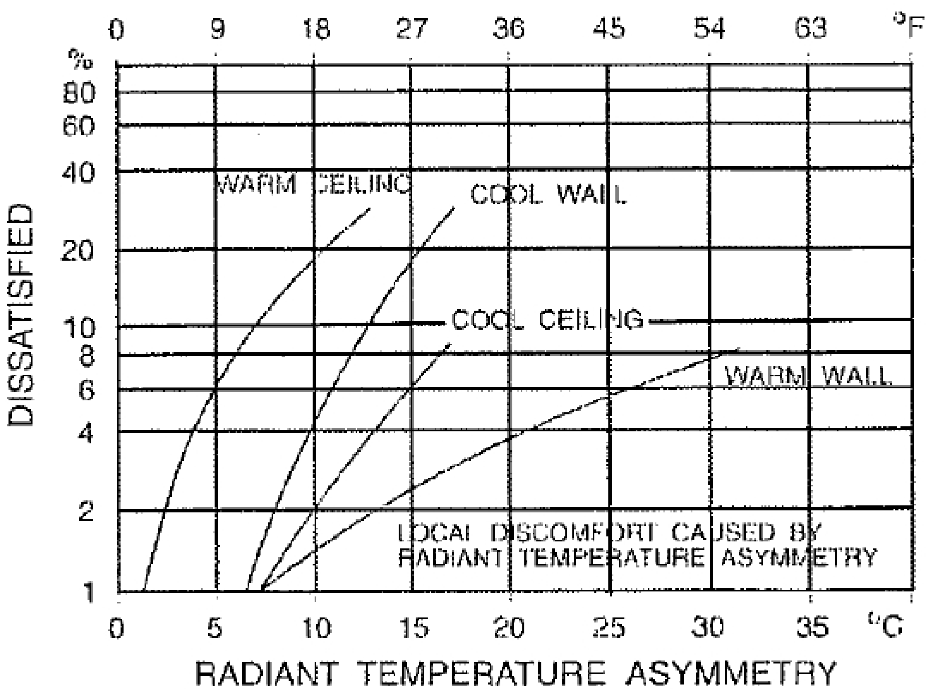

Figure 49. Human focus groups were surveyed for people's subjective comfort level when exposed to conditions of radiant temperature asymmetry in horizontal (wall) and vertical (ceiling) directions. (Reproduced by permission from ANSI/ASHRAE Standard 55-2004, Thermal Environmental Conditions for Human Occupancy, ©American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., www.ashrae.org.)

The second finding above corroborates testimony from people that they are extremely comfortable inside thermally massive building envelopes, in which we have shown (see section 6.6) that walls tend to be warm and free of local cold spots. Indeed these walls, already warm and radiating heat stored from the sun, will minimize radiant loss to the outside from a wall-integrated hydronic heating system, enhancing the performance of that system.

The research we have just described, and notably the fourth finding listed above, is part of the reason why Europeans are beginning to favor wall-integrated radiant heat systems.

One option is to use baseboard or stand-up hot water radiators. One can also choose micro-tubule in-wall hydronic heating and cooling systems, such as made by a number of companies in Europe and imported to this country through at least three distributors (see below). These tubules can easily be embedded right into a clay plaster finish on the inside of your exterior walls if the wall material is low-density fiber-cement or AAC, or else surface-mounted as pre-fabricated units.

Regarding the use of in-floor heat as is currently popular among green building enthusiasts in America, some in Germany contend that this form of radiant heat can cause problems with occupants regulating their body temperature, since the feet are considered instrumental in this process. Some in Germany feel that the lowest third of the body is kept too warm by in-floor heating, which disrupts the cardiovascular system and can cause varicose veins. This may not be a significant problem if the temperature of the in-floor heat is kept at a relatively low level.

To counteract this effect, several European countries have restricted or banned, or are considering restricting or banning, the use of forced-air convection heating/cooling in schools, hospitals and nursing homes due to its deleterious effects on human health, according to George.

As shown above, European builders have found that heat radiating off a vertical wall is more evenly distributed over the entire height of a person than heat coming up from the floor. In-wall heat has therefore been found to be healthier than in-floor heat.

Several companies in America import in-wall capillary tube mats made by the BEKA Klima-Komfort company of Berlin ((030)-474-11-31; www.beka-klima.de). These include BEKA USA (623-266-9844; www.bekausa.com) in Arizona, soon to also be a manufacturer of the product; Rudek Construction Service Inc. in Chicago (773-764-8685; www.naturalcooling.com); and Radiant Cooling Corporation in Chicago (773-281-2950; ww.radiantcooling.org). Radiant Cooling Corporation also carries a similar product made by a French company, KaRo Systèmes (http://www.karosystemes.com/eng).

According to the website for the BEKA company in Berlin, Germany (www.beka-klima.de),

> Water transports heat 1000 times faster than air does [due to greatly improved conduction to the solid mass] and therefore it is many times more effective.… Water is circulating in these tight capillary tube mats, which is not much warmer or colder than the ambient air. This type of temperature controlling follows the model of the human capillary receptacles.

BEKA® and KaRo® capillary tube mats are embedded in plaster on either the wall or ceiling, but when they will be used for heating we recommend only wall installation, based on the research described above. BEKA also makes pre-fabricated units that can be surface-mounted on walls or ceilings for “dry-built” installations. They come with a 15-year warranty.

GreenKrete in Iowa (866-306-0939; www.greenkrete.com) is pioneering the use of in-wall heat and cool in this country by embedding micro-tubules in clay plaster covering their GreenBlok® wall blocks. Finally, Variotherm is the oldest supplier of in-wall systems in Europe. Even though their product is not available in this country, their website (www.variotherm.at) has a wealth of information.

During the cooling season, in-wall tubules can carry cool water if a geo-thermal heating system is used. When embedded in clay, the cool water does not cause beading of condensed moisture from indoor air on the wall. Instead, clay absorbs moisture without wetting the wall or causing damage. Homeowners with in-wall hydronic heating and cooling systems report no condensation when cooling their home in summer. This also reduces the load on a conventional central or wall-mounted air conditioning system.

Finally, consider the following recommendations:

- Geothermal heat pump systems are very cost effective. Many electric utility companies offer rebates on the cost of installation, making geothermal heat pumps competitively priced when compared to a traditional gas-powered furnace.
- A sealed loop combustion domestic hot water system should also be installed.
- Locate the domestic hot water heater centrally within the home.
- Insulate the domestic hot water heater and heat exchanger tanks with a well-fitted insulating jacket.
- Insulate the two feet of hot and cold water pipe closest to the hot water heater and heat exchanger with pre-cast foam insulation and with heat traps to prevent standby convective heat loss from the hot water heater tank.
- On-demand hot water heaters are an energy-efficient option.
- Install a hot water demand re-circulation system on the faucet or shower furthest from the hot water heater.
- Install a heat recovery device on at least one shower drain to recover heat from the drain water.
- Place the chimney, if possible, within the building envelope to add to energy efficiency.

14.7 Healthier Forced-Air Systems

Forced-air heating and cooling, while quite popular and affordable, has definite unhealthy side effects that have been covered in the previous section. When you do choose to use forced air, however, building biologists make a number of recommendations to counteract the drawbacks and create healthier indoor air quality for occupants.

- The central air conditioning component of the HVAC unit can be sized substantially smaller if you follow the steps in this manual, creating significant savings in electric cooling costs and reducing the dissemination of airborne contaminants.

- In some cases forced-air systems can be eliminated altogether and added only for the purpose of providing fresh air exchange. Having less forced air flow also reduces the generation of unhealthy positively charged ions.

- Our first choice for all supply and return ducts and plenums is sheet metal. Fiberglass board should not be used for ducting under any circumstances. Also, avoid fiberglass-lined flexible ducting due to the possibility of fiberglass fibers entering the air stream if tears develop in the plastic lining. Also, flexible fiberglass ducting cannot be cleaned by duct cleaning companies because the plastic lining is too fragile and will tear.

- An acceptable alternative is semi-flexible air ducts made by Superior Air Duct L.P. of Houston (713-682-3828; www.superiorairducts.com). Their "Semi-Flex" ducting is lined with cotton insulation rather than fiberglass. The product comes with a ten-year warranty, is treated to be mold and vermin-resistant, stops condensation, is flame-resistant, and is much more sturdy than fiberglass-lined flexible ducting. The plastic lining of these ducts is strong enough to be cleaned by duct cleaning companies, a real plus from our standpoint.

- When you insulate the outside of metal ductwork, use cotton insulation rather than fiberglass. Cotton duct liners are available from Superior Air Duct L.P. Provide the company with dimensions. Cotton has been shown to be resistant to mold when used as an exterior duct. A study was conducted for Bonded Logic by. The study, entitled "Resistance to Microbial Growth in UltraTouch® Cotton Insulation in a Controlled Environment," compared the resistance of cotton duct insulation to fiberglass. Out of seven mold species introduced under controlled conditions to cotton and fiberglass, only one showed any significant growth on UltraTouch® compared to five on fiberglass. (Contact Bonded Logic, 480-812-9114; www.bondedlogic.com – Study by Laboratory Services of Pompano Beach, Florida, reported on January 9, 2003).

- All duct joints should be sealed with mastic (such as RCD Mastic No. 6), whether the ducts run in an attic or crawl space. This keeps humidity, contained in hot attic air, from entering the air ducts through gaps in the seams during air conditioning season. Mold propagates due to moisture condensation within the cooler air ducts. Seal all seams to prevent mold.

- Likewise in winter months, seal air ducts in crawl spaces to keep warm moist air from leaking out and condensing on the surfaces of cooler stem walls, causing mold.

- If the air handler is located in a crawl space, try to allow easy access by occupants for frequent changing of the air filter.

- A natural gas or propane-powered furnace should be 80% efficient at minimum. Use a blower fan for drawing combustion gasses over the heat exchanger. Preferably choose a furnace with 90% or higher efficiency, containing a sealed-loop combustion system. The furnace fan can have an electrically commutated motor, which uses ⅓ to ½ less electricity than a conventional furnace (less than 500 watts). These highly efficient furnaces only have a two to three year payback.

- Use pleated furnace air filters, such as those made by 3M, rather than spun glass filters. 3M's filters are marketed under the Filtrete® name and are available in the 1000 or 1250 series. Choose these or an equivalent pleated filter with a Minimum Efficiency Rating Value (MERV) rating of at least nine or ten. MERV is a rating system developed by ASHRAE as a way to compare furnace filters. Spun glass filters, while quite inexpensive, only have a MERV rating of 2 or 3 and allow up to 90% of dust particles smaller than one micron to pass through. Sub-micron particles make up the bulk of the dust that we breathe. They reach the deepest parts of the lungs and cannot be easily expelled. Replace these filters more often than the manufacturer recommends (three months). We suggest every 30 to 45 days, especially if you have children and pets. Check with your HVAC contractor to be sure that the tight weave of the 1250 series Filtrete® furnace filter will not strain your fan motor. Some claim that a heat exchanger within the furnace can crack due to too tight a filter.

- Four inch pleated filters have a high MERV rating and do a good job of filtering air, but the manufacturer recommends they only be replaced once a year. This is far too long and we recommend you change these at least once every six months, and more often if possible. They are pricey to replace ($30-40) but a filter caked with dust likewise puts a strain on your fan motor and does not adequately filter your air. One inch filters are just as efficient and can be replaced more often.

- We recommend a whole house humidifier attached to the HVAC unit. These units keep indoor air humidity at comfortable and healthy levels in winter. This keeps mucous membranes moist reducing respiratory problems. Do not select a model with a water reservoir, because mold can grow in the standing water in the reservoir. Choose a flow-through model such as those made by Aprilaire (www.aprilaire.com) and other companies.

- Regarding air-to-air heat exchangers, we recommend an Energy Recovery Ventilator (ERV) rather than a Heat Recovery Ventilator (HRV). ERVs capture indoor air humidity in winter and transfer it to incoming fresh air along with the captured heat. They also extract humidity from outside air in summer by the same mechanism, but in reverse. HRVs do not extract humidity, they require a drain pan, and they can only be mounted horizontally. ERVs do not have a drain pan and can be mounted in any orientation, which is a plus if space limitations are a concern. ERVs are made by Aprilaire (608-257-8801; www.aprilaire.com) and by RenewAire (800-627-4499; www.renewaire .com), and other manufacturers.

- Install an electric or ultra-efficient gas-fired hot water heater. If using a gas model we strongly recommend that you have a closed-loop combustion system, which includes an exhaust fan.

- A solar hot water heat exchanger can be added as the primary energy source for your domestic hot water, supplemented by electricity or gas. These units have a two- to three-year payback. Contact a local HVAC contractor who is familiar with this option.
- The HVAC air-conditioning cooling coil (evaporator) box, or plenum, and the blower fan box should not be insulated on the inside with fiberglass. Most, if not all, HVAC units come with a fiberglass board glued to the inside walls of the plenum. As a result, fiberglass fibers and tiny shards of glass enter the air stream because the fiberglass used is lower grade than the spun glass batting in wall insulation. The solution is to remove the fiberglass and replace with non-fiberglass insulation mounted to the outside of the furnace, if needed (although this may void the unit's warranty). HVAC contractors recommend TekFoil® as an exterior insulation. TekFoil® avoids the fibers in the air stream but does not provide sound dampening, a consideration if the HVAC unit is located within a utility closet in the living space.
- Cotton insulation is now being installed at the factory in the plenum of HVAC units by more and more manufacturers which can be left in place if already present in a new unit. If a new unit comes with fiberglass, however, it is better to remove the fiberglass and not install cotton inside the plenum. This avoids introducing another type of fiber into the air stream, this time from cotton. If thermal insulation is needed, choose the external application of TekFoil®. If sound dampening is an issue, then do install cotton inside the plenum rather than fiberglass to dampen the sound. Contact Bonded Logic (480-812-9114; www.bondedlogic.com) or InsulCot (806-777-2811; www.insulcot.com).HVAC representatives at recent ASHRAE shows have taken an interest in UltraTouch® as a replacement for fiberglass because they see fiberglass in the air stream as the next area of product liability in the construction industry. The HVAC companies want to be proactive and make the switch from fiberglass to cotton now. The Titus Company, a maker of HVAC units, already uses a cotton product in their plenums called Envirolock®, made by a subsidiary of Bonded Logic. It is made of natural white mote cotton, which is otherwise left on the stalk to become silage. It is now being harvested for industrial purposes.
- Your HVAC contractor can also install cleaning access plates (one for each side) in the coil box for easy and frequent servicing.
- If the HVAC unit is mounted in the attic, as it usually is in warmer climates, do not use loose blown-in insulation for the attic floor, particularly fiberglass. Fibers will enter the air stream and be drawn into the living space. Use rolls of cotton batting instead.
- Air-conditioning Freon lines that run between the outside AC compressor and the indoor HVAC unit should not run in any floor or wall located under, behind or within six feet of the location of any bed. This is because the compressor motor acts as an intense magnetic field source that induces current flow on the closed loop consisting of the Freon lines and the grounding conductor. This current causes a magnetic field that could extend several feet into the bedroom area and must be avoided. Building biologists recommend the use of air purification

systems to provide even higher quality indoor air, particularly if forced-air heating and cooling systems are used and you live in an area with airborne mold and pollutants.

- Portable or HVAC-mounted purification/filtration units are manufactured by several companies. Contact a local dealer of these products or your local building biologist (http://www.buildingbiology.net/bbinco.html) for more information.

14.8 Cooling

For summer cooling, alternative strategies to substitute for or augment costly and unhealthy forced-air central air conditioning include:

- As discussed at length in chapter 6, build thicker outer (and inner) walls in which thermal mass stores overnight cool and radiates the cool during the day.
- Design roof overhangs, awnings or trellises, and the planting of shade trees.
- Install smaller and fewer west-facing low-E windows with mini blinds between panes.
- Install plastic vent chutes in the eaves of the attic above the insulation to vent the soffits and keep your attic cooler.
- Provide sufficient cross-ventilation through screened windows and doors placed along the east-west and north- south axes.
- Install a cupola or monitor / skylight in a ceiling over your living space to provide a whole-house chimney effect. Use a remote-controlled opener and a humidistat-controlled motor to close the skylight in case of rain. Limit the skylight to 6% or less of the floor square footage of the room in which it is located to avoid heat loss.
- Use whole-house ceiling fans.
- Install a solar-powered attic fan.
- Include an adequate number of soffit vents. A ridge vent along the crown of the roof is best. If your attic is well-ventilated, you will feel a slight breeze while standing in it when the wind blows outside.
- Geothermal heat pumps are an excellent choice for natural summertime cooling in hydronic heating and cooling systems. The water / food-grade glycol mix in the closed loop system comes into the home at a steady 55-60 ˚F, the year-round temperature of soil below the frost line. This mixture circulates through a heat exchanger and up into the floors, walls or ceilings in summer to provide radiant cooling. If wall tubules are embedded in clay plaster, no condensation of moisture will occur on walls.

- Apply a nontoxic paint to the underside of your attic roof containing Radiosity Radiant Barrier®, a powder made of tiny hollow glass beads (www.radiosity.biz). This saves 15-20% on cooling costs. Radiosity® reduces attic temperatures from an average of 170 ˚F down to 130 ˚F., without also installing an attic fan. Purchase the glass bead powder and mix it right into any paint.

- Consider an earth tube cooling system – contact Larry Larson in Fairfield, Iowa, a designer and installer of earth tube systems for natural cooling (641-472-4953).

- Use a window air conditioner unit as a last resort. Be sure to keep filters and drainage tubes clean, clear and free of mold.

- If central air conditioning is used, it only needs to be supplemental. Also, the HVAC unit can be sized smaller if you implement the strategies in this manual.

- Consider using radiant cool water / hot water woven “mats” made with 1/16- inch diameter tubes installed behind wallboard or natural plaster walls or ceilings such as made by KaRo Systems in Chicago. As noted above, these tubules can easily be embedded right into a clay plaster finish on the inside of your exterior walls if the wall material is low-density fiber-cement wall form, AAC block or GreenBlok®.

- Radiant cooling is comfortable, draft-free, and quiet. It makes efficient use of the body’s natural process of dissipating body heat, 50% of which is done by radiant cooling and only 30% by convection cooling. The final 20% occurs by evaporation through sweat and breathing. Thus forced-air convection cooling does not address the most common way the body cools itself, by radiation. When using these systems an optional smaller sized forced-air system is only needed for fresh air supply, eliminating contaminated air that is otherwise cooled in a forced-air system.

- In addition, when micro-capillary mats are mounted on the ceiling for added cooling, air stratification is limited and the ceiling actually absorbs heat generated by people and objects in the room. Mats mounted in wallboard can be applied to existing walls as a retrofit. Water pumps cost 30 to 45% less to run than air handler fans. Generally you see a five- to seven-year payback. In the south where humidity is more of a problem, installation needs to be precise and an air handler or fresh air supply system is necessary to remove moisture and avoid condensation.

- Useful articles on radiant cooling systems are provided at the Oikos website[285] and at Toolbase Services, a resource provided by the National Association of Home Builders Research Center.[286]

[285] See “Finally a System that gives you both Indoor Air Quality Through Radiant Heating & Radiant Cooling; No Draft, No Noise” at http://oikos.com/products /mechanical/karo/.
[286] See “Hydronic Radiant Cooling” at http://www.toolbase.org/Techinventory/Tech Details.aspx?ContentDetailID=779&BucketID=6&CategoryID=6.

14.9 Integration with Ancient Traditions of Design

Building Biology® is compatible with ancient traditions of design and construction, including Sthapatya Veda from India and Feng Shui from China. It also supports the premises and practices of modern green, sustainable design. In fact, Building Biology® completes a triad of design and construction principles offered today to improve standard construction; that is,

1. Sustainable and ecological design
2. Ancient principles from India and China as well as native practices of all lands
3. Germany's Baubiologie, known in America as Building Biology®

Building Biology® strives to maintain the health of occupants and construction workers on all levels and makes both sustainable and ancient design even healthier. Many readers of this manual are already familiar with green and ecological design as well as Feng Shui, but a few words will be presented here about Sthapatya Veda (or Vedic, or Vastu) design. The author would like to thank Jonathan Lipman, AIA, Fairfield, Iowa, as well as authorities on this subject in Vlodrop, Holland, for reviewing and verifying the information that follows.

Sthapatya Veda is associated with the ancient Vedic (pronounced *Vay*-dic) civilization of India. It is based upon the solar, lunar and planetary influences upon the earth, and strives to connect individual life with Cosmic life. It focuses on the way the sun affects occupants in their home as the sun moves daily from east to west. The goal of Sthapatya Veda is to promote the health and enlightenment of every occupant by providing proper orientation of the plot and home, proper placement of rooms, and the proper dimension of walls and rooms within the home. All this is done so that you avoid influences considered to be inauspicious and make use of the most supportive influences.

Fairfield and Vedic City, both in Jefferson County, Iowa, are two of the primary sites where Sthapatya Veda is being revived in this country. Hundreds of homes have been built in the past few years following these principles with universal reports of improved health and family life.

Informal studies have been conducted confirming these benefits, including an interesting survey conducted by a resident of Fairfield, Dr. Veronica Butler, who practices in nearby Ottumwa, Iowa. She found that her patients who routinely used a south entrance to their home, considered by Sthapatya Veda to be the one direction to avoid for your entrance, had the highest statistical incidence of ill health, divorce, break-in and bankruptcy. Most of the patients surveyed lived in Ottumwa, rather than Fairfield, and knew nothing about Sthapatya Veda. One is advised to orient one's house so that the front door is to the east to catch the first rays of the rising sun, and all the homes in Fairfield and Vedic City built according to this tradition face to the east.

Many people have asked that some of the essential elements of Sthapatya Veda be covered in this manual, so a few of the generally published elements are included here to give the reader a flavor of what is considered important. While Feng Shui is already widely accepted in this country and is very valuable, I highly encourage all architects and new homeowners to also look into using Sthapatya Veda, or Vastu, for the design of any new building whenever possible. Take advantage of the many benefits this ancient tradition has to offer.

A few examples of the principles to achieve what is known in India as "proper Vastu" include the following:

- The plot upon which the house is built should ideally be oriented along the cardinal directions (north, south, east and west) and be as square or rectangular as possible. Avoid angled and irregularly shaped plots.
- If the site is not flat, it should slope ideally to the east, northeast, or north. A plot that slopes to the south should be avoided, as this drains away wealth and energy.
- Bodies of water, if they are near the home, should be located to the east or north. It is recommended that bodies of water to the west or south be avoided.
- No matter what the orientation of the plot, the occupants should ideally enter the home from the east, while a north entrance is considered second best and still auspicious.
- A southern entrance is to be avoided if at all possible.
- Attempt to obtain cross ventilation in all major rooms and hallways. Maintain sight lines through the house along east-west and north-south axes using windows and glass in your front door.
- Proportion is very important and is beyond the scope of these introductory remarks. One needs to consult professionals in this field to fully avail oneself of the benefits of proper dimension.
- Because the sun generates different qualities of energy on its daily path from east to west, a home should be designed so that the placement of different rooms in the home corresponds to the change in the sun's energies. This permits natural law to support all of the activity in a home, such as the promotion of good digestion when the kitchen is in the southeast corner. The master bedroom is ideally located in the southwest corner, and one's prayer, contemplation, study or meditation room should be in the northeast corner.
- Advice is also provided on the most auspicious time for such critical events as the beginning of construction and moving into the home.

These are general guidelines only and are not meant to be a comprehensive representation of what Sthapatya Vedic home design has to offer. Specific dimensions and other recommendations are necessary to enjoy what this ancient practice has to offer. To obtain the maximum benefits one should consult a fully trained expert in the field.

For more information, contact Maharishi Vedic Architecture® at www.vedicarchitecture.org. Jon Lipman, AIA, in Fairfield, Iowa, one of the preeminent authorities on the subject, can be reached at 641-472-9605.

A revival of the practice of Vastu has also been undertaken by Professor Dr. Jiten Bhatt of Delhi, India. Dr. Bhatt traveled to Egypt and combined his knowledge of both Vastu and Feng Shui with the pyramidal traditions of ancient Egypt. He calls this amalgamation "PyraVastu," using the technologies of the pyramids to rectify incorrect Vastu in an existing home or property when it is not possible to build with correct Vastu in the first place. Contact www.pyrahealth.com. Experts trained in this field are also available in the USA, including Swami Ananda Veetrag in Bloomington, Minnesota (952-893-0134 or 612-812-5496). Swami consults with individuals nationwide to help in the proper design of the home and the rectification of existing structures.

You may also find the following individuals helpful. Both are trained in Vastu design and construction techniques:

Ronald N. Quinn, Builder, Colorado (970-872-3689; rvaastu@tds.net)

Michael Borden, Vastu Design, Fairfield, Iowa (www.vastu-design.com)

Chapter 15. Examples of Homes Built with Low-Density Fiber-Cement Wall Forms

Many homes were built in Fairfield, Iowa and surrounding communities in the early 1990's using Faswall® brand low-density fiber-cement wall forms. Durisol® was not widely known to the community at that time.

Many homeowners like the performance of Faswall®. On the other hand, some homeowners, according to George Swanson, had only moderate improvements in performance with their Faswall® homes compared to conventional homes. Several of those homes were built on a low budget using inexpensive doors and windows, which affected thermal performance. As a result the homes leaked cold air.

On October 20, 2003 one of the authors inspected and interviewed the owners of two homes in Fairfield, Iowa built with Faswall® wall forms. He learned the following:

Iowa Home #1. Faswall® was used only below grade with a stud frame first floor above grade. The home was built approximately ten years before the visit. The home had a walk-out basement with two walls below grade. The owners lived in the basement as they completed the first floor.

The owners decided to put a plastic vapor barrier and sheet rock nailed directly to the inside of three of the Faswall® foundation walls. Exposed Faswall® was still present along the fourth wall, which was below grade. Note that a plastic vapor barrier is not needed, and in fact, discouraged by many builders, in the construction of Faswall® and Durisol® foundations and walls.

The owners did experience mold in the basement but only in the ceiling insulation material. This resulted from a water pipe leak directly above the affected area, as well as from carpeting soaked by rain water that blew in through windows during a severe summer thunderstorm while the owners were out of the house. No moisture intrusion or mold growth was reported through or on the Faswall® foundation walls.

Moisture readings were taken along the inner surface of the Faswall® wall using a Protimeter Survey Master. The meter was set at the radio frequency setting to read moisture levels one quarter to one half inch deep within the material.

Readings were 7-9% wood moisture equivalent (WME), considered well within the dry range. In contrast, typical moisture readings of below grade concrete foundation walls in Iowa consistently run in the 18 to 35% WME range, considered moist and capable of supporting active mold growth.

The owners of the house were quite happy with the performance of their Faswall® basement foundation wall.

Figure 50. Exposed Faswall® foundation wall in basement kitchen of home #1.

Iowa Home #2. This 2200 square foot house was designed and built by George Swanson in approximately 1993. Faswall® wall forms were used below and above grade. George used his alternative protocol for insulation in the core, using cellulose rather than rockwool. Cellulose was also used as insulation in the attic, 18 inches thick.

Figure 51. Faswall® home #2 with wood siding.

The interior walls were covered with sheet rock nailed directly to the Faswall® forms. No plastic vapor barrier was used. The exterior was covered with wood siding. The basement was again a walk-out design.

The owners stated that during their ten-year occupancy their heating bills had always been lower than their friends and neighbors. The highest monthly amount was approximately $180 in the winter some years before. Windows were caulked in 1993 and a wood stove was installed in the basement in 1999, which further lowered their heating bills.

The owner stated that construction of the house began the summer of the great flooding of Iowa in 1993 and that the builders had to drain the foundation site several times. Laying of the foundation did not begin until late summer and the house was completed in December. In spite of the abnormally wet conditions the owners moved into a house with a dry basement.

The basement wall has always been straight with no buckling. The same is true in house #1. There have been no reported water leaks or seepage through the Faswall® foundation at either house.

Moisture readings were taken at the second residence along interior surfaces of below-grade exposed Faswall®. They were again found to be in the 5-7% moisture range, considered to be a dry wall and well below readings found in typical basements in Iowa.

Figure 52. Taking moisture reading of Faswall® foundation wall at Home #2.

The owners stated, "We like the breathability of the Faswall® and the fact that it is environmentally safe and nontoxic. People like the feeling in the house when they visit."

The neighboring house immediately to the south is also a Faswall® home built by George Swanson. It is finished with stucco. The home was not toured but is pictured below.

The owner stated he had Faswall® below and above grade. He used a wood stove to heat so he could not give comparative data on heating bills but he was very satisfied with the Faswall®'s performance.

Figure 53. Neighboring Faswall® house with stucco siding.

Iowa Home #3. The author also spoke with the owner of another Faswall® home in Fairfield that was not visited. The owner mentioned several interesting facts about Durisol®, including the fact that the country of Switzerland certifies Durisol® houses to last for 400 years. Also he attended a building convention in New York (he owns a company that repairs stained glass windows) and at another booth sat an Israeli maker of Durisol® who was touting the product as being "bomb-proof." He said the man had photos of a Durisol® house built in Israel that reportedly took a direct missile hit that merely chipped the outer stucco.

Part Three. CONSTRUCTION PROTOCOLS

Now that you have a thorough understanding of the science and practical application of breathable walls, we present here in Part Three a condensation of the protocols presented in the previous chapters.

We start with a discussion of steps you can take to minimize the toxicity created in a home as building materials are assembled on the job site. This also safeguards the health of workers (chapter 16).

We then present protocols for each step of the building process, consistent with the sequence generally followed on the job site. We start with protocols for the slab and foundation (chapter 17), with the primary aim to allow for breathability while maintaining thermal performance. We present our recommended protocols for high water tables and radon and other soil gas mitigation. We present alternatives to steel rebar, to eliminate exposure to unwanted electric and magnetic fields. We also discuss ways to avoid mold in crawl spaces. We complete chapter 17 with our recommendations for finishing the inside surfaces of the foundation wall in ways that prevent mold.

The final chapter (chapter 18) contains specific protocols for all above-grade construction discussed in this manual. This includes a reprinting of our summary of the installation steps for low-density fiber-cement wall forms. We also present an alternative protocol, developed by George, for the infill of these wall forms that avoids Portland cement and rockwool inserts for low-rise buildings. We also provide protocols and resources for many of the materials discussed in Part Two, including autoclaved aerated concrete, magnesia-based sheeting and exterior and interior finishes. *[This, and other information in this Part, will be expanded in the published edition. –Ed.]* We also present George's alternative protocol for wood-frame construction, using wood studs, magnesia, clay, borax and infill insulation, either cotton or wet cellulose.

Chapter 16. Worker and Environmental Protection during Construction

Protecting the health of workers on the building site environment is a very important aspect of our construction protocol. Exposure to outgassing of toxic building materials and particulates are only a few of the potential exposures. Significant material particulates and residue can also remain on site, such as in air ducts, after construction is completed. This can affect the health of the new owner and their family when forced air is run through these ducts. We encounter this on our environmental home inspections.

Our recommendation is to have contractors and their trades people observe the following guidelines to prevent these exposure problems (based in part on the construction site recommendations in *Prescriptions for a Healthy House* by Paula Baker-Laporte, Erica Elliot and John Banta:[287]

- Do not run gasoline-powered electric generators inside the house once enclosed. Run them outside
- No smoking is allowed on the building site
- Provide workers with N-95 respiratory masks, which are more effective than so-called "painters masks"
- All workmen should immediately clean all spills onsite and report them to the general contractor
- Cover and protect all air ducts and plenum of HVAC unit from contamination from building dust and debris. If the HVAC system is to be run during construction make sure a good pleated filter is in place in the air return (3M Filtrete® 1250 series 1" pleated filter or equivalent; not spun glass filters) and place fabric filters over all return air vents. Clean all ducts before occupancy if unit is run during construction or vents are not covered.
- In all cases clean out construction debris that fall into floor air vents after house is finished.
- No insecticides or fungicides are to be used onsite without prior written approval. Choose nontoxic alternatives.[288]
- Ventilate the house with fresh outdoor air for a full seven days prior to occupancy.
- Be sure all nontoxic products specified in the plans by the client, architect / designer and general contractor are not substituted with more toxic alternatives by a sub-contractor without prior written approval of all parties concerned.

[287] See http://www.newsociety.com/bookid/3997.
[288] See the Biocontrol Network website: www.biconet.com.

Chapter 17. Below-Grade Envelope

17.1 Slab

See chapter 11 for a discussion of the rationale behind these protocols, most notably to eliminate mold and to counteract the health detracting influence known as "concrete sickness."

Slab Protocol:

1. Place one to four inches of pre-crushed chips (typical dimensions one inch long by ⅜ inch wide) of Durisol® or Faswall® low-density fiber-cement over a level, one to two inch layer of lightly compacted bed of sand, fine gravel or sandy loam on bare soil. The colder the climate, the thicker the layer should be. (Both manufacturers listed in section 8.8 can provide inexpensive pre-crushed or new stock of chips in 2 cubic yard "Gaylord" bags.)
2. Broadcast or "dust" over the chips with about a quarter inch layer of Portland cement
3. Lightly hose over cement until wetted. Allow to cure overnight. Cement will be barely able to be walked on but will be stable enough to walk on
4. Set forms.
5. Add breathable landscape "filter cloth" in place of a vapor barrier (retarder).
6. Pour concrete slab. (If you are pouring an at-grade slab in areas prone to flooding, provide a French tile drainage system around the perimeter of the slab that drains to daylight or an external sump pump to avoid standing water around the perimeter of the house)
7. Once cured you may lay cork, tile, colored concrete, magnesia-based terrazzo or wood finished flooring. We do not recommend any carpeting in basements. Use nontoxic concrete coloring and sealers, such as from the AFM Company (619-239-0321; www.afmsafecoat.com).
8. For extra EMF protection consider laying magnesium oxide board on top of the concrete slab to further mitigate the effect of "concrete sickness." Use Strong-Enviro Board® or DragonBoard®.

Both Durisol Building Systems and ShelterWorks can provide inexpensive pre-crushed or new stock of chips in 2 cubic yard "Gaylord" bags. Then add concrete to get it to bind.

You need to learn how to do this. The cost is about 40% more than a conventional floor. Call George Swanson for details (512-653-8624; gps@flash.net).

Vent the edge of the slab in line with the one to four inch chip layer using two-inch diameter by twelve-inch long tubes placed every four feet and filled with cement-bonded wood fiber chips. From the outside of the slab edge, the opening of the tube is simply stuccoed over with breathable (magnesia or lime) stucco at the same time the rest of the wall above is stuccoed.

Alternative Wood Chip Terrazzo Slab Protocol

This protocol is intended to provide a more durable slab that breathes better than a conventional one, even when using the protocol outlined above

1. Lay one to two inches of dry, pre-crushed chips (Faswall® or Durisol®) over a level, compacted sand or bare soil base.
2. Broadcast or "dust" over the chips with about a quarter-inch layer of Portland cement, or if budget allows, MgO cement.
3. Lightly hose over cement until wetted.
4. Allow to cure overnight. Cement will be barely able to be walked on but will be stable enough to allow you to do the following:
5. Set forms. (From this point on the protocol differs from the one above)
6. Mix wood chips 60-70% with concrete 30-40%.
7. Tamp and trowel into place as level as possible.
8. You can also dust a thin layer of magnesium oxide cement on top of the concrete slab, as described above.
9. Once cured lay such solid surface flooring as cork, tile, terrazzo, or wood as optional finished flooring.

An alternate way to "treat" wood chips is to soak the chips in a bath of 50% clay, 48% magnesia powder (Bindan or Grancrete), and 2% borax, watered to a thick milky consistency. Thoroughly dry chips before placing.

17.2 High Water Table and Radon Control Slab

The protocol for a basement with a high water table or high soil radon content is to create a moisture barrier and a "breathing" slab assembly as follows:

1. Lay Delta® Drain air-gap drainage membrane[289] (with dimples up) horizontally over a level, compacted sand or bare soil base.
2. The geotextile fabric bonded to the flat tops of the dimples keeps the concrete out of the air space between dimples during the concrete pour.
3. Lay 1 to 2 inches of dry low-density wood fiber-cement chips over the Delta® Drain membrane.

[289] Available from the Cosella-Dörken Company (888-433-5824, www.deltams.com).

4. Broadcast or "dust" over the chips with about a quarter inch layer of Portland cement.
5. Lightly hose over cement until wetted.
6. Allow to cure overnight. Cement will be barely able to walk on but will be stable enough to allow you to do the following.
7. Set forms.
8. Pour concrete slab.
9. Remainder of protocol is as above.

17.3 Alternatives to Steel Rebar

Our profession suggests that those individuals who are electrically sensitive use fiberglass rebar rather than steel. There are several forms of fiberglass rebar. They include C-bar, a non-metallic fiberglass rebar and fiberglass fibers that can be mixed into the concrete for reinforcement. Composite rebar is available in North America from Trancels Construction Technologies, Concord, Ontario (888-726-2357; www.trancels.com). V-Rod®, a fiber-reinforced polymer, is made by Pultrall (www.pultrall.com) and marketed by Trancels. V-Rod® is a non-corrosive, electromagnetically neutral alternative to steel rebar. V-Rod® is one quarter the weight of steel with twice the tensile strength and provides significant cost savings compared to steel.

One word of caution. You do not want an electric charge to flow onto steel rebar. The 2005 version of the National Electric Code (NEC) requires that the electric panel be bonded to metal rebar in concrete footers as the primary "system" ground to earth. This supplements the earth rod outside under the electric meter. Bonding to metal rebar is recommended because more and more homes are built with plastic water pipes under the front yard, not copper. For decades bonding to the metal water pipe was the primary "system" grounding path, even the exclusive grounding path until earth rods were also put in beginning in the 1960s. The problem is that electric current will travel on all available paths to get back to the source (the electric utility transformer), and some current will flow on the water pipes under the yard, the street, and back through neighbors' homes to the transformer. This creates unhealthy magnetic field exposure in homes connected to city water mains by metal pipes.

While we recommend plastic water service supply pipes under the front yard in order to isolate the house from this parallel path for return current to flow, we *do not* endorse bonding to metal rebar, because it, too, can create a parallel path for electric current to flow. This time, the current flows out the concrete slab, which does conduct electricity, and through the earth to the ground rods of the utility poles or pad-mounted transformers at the street. This is known as "stray voltage" (which is really "stray current"). Likewise, this current flows throughout the metal rebar of entire foundation, and electro-magnetically sensitive people are made ill by this current flowing on paths where it does not belong.

Our solution is to bond to a single, separate 20-foot section of metal rebar in its own concrete caisson, buried in the back yard separate from the concrete of the footer and slab. Second best is to bond to an isolated, separate 20 foot section of rebar in the footer that is *not* connected to the rest of the rebar in the foundation. As an example of code opinions on this issue, bonding to a single length of rebar encased in a separate caisson has been approved by electrical inspectors in the state of Minnesota, and bonding to an isolated piece of rebar without connecting to the rest of the rebar is allowed by the Minnesota Electrical Code.[290]

Where horizontal steel rebar meets vertical steel rebar, you can also isolate the rods from each other during construction by inserting a piece of rubber from an old tire between the rods. This creates a break in electrical conductivity between rods.

Another alternative to steel rebar is on the horizon. The Russians are using extruded basalt fibers the size of a human hair spun together into a "pseudo glass" fabric that can be used as rebar. Basalt can be made into every shape steel is made into, such as beams and rods. It is four to seven times stronger than steel with 89% the weight, and four to five times the strength of fiberglass. The threads of the rock are entwined together and encased depending upon the needs. It is used extensively in Eastern Europe and is now available in this country as a ceramic fiber-polymer composite material called Sudaglass® (281-496-5427; http://www.sudaglass.com/rods.html).

17.4 Foundation and Stem Wall

Although our profession generally does not recommend basements nor crawl spaces, this protocol is included here in cases where a basement is constructed and to give guidance on our protocols for crawl space and stem wall foundation construction.

The following protocol is provided by Durisol Building Systems. We recommend that you download and thoroughly review Durisol's Technical and Installation Guide.[291] *[In the final publication we intend to incorporate a similar protocol recommended by the K-X Faswall International Corporation. An updated Faswall Technical Manual is available by contacting ShelterWorks. –Ed.]*

Choice One:

1. Below grade use ten-inch R-8 uninsulated Durisol® wall forms (that is, uninsulated with rockwool insert).

[290] See Fall 2005 Department of Labor and Industry Electrical Licensing and Inspection Newsletter, p. 6, "Concrete-Encased Electrode Requirement: Clarified," http://www.electricity.state.mn.us/pdf/eli_fall05.pdf: "If either a separate bare copper conductor or steel reinforcing rod is present or installed, the NEC does not require the portion used as a concrete-encased electrode to be bonded to other reinforcing steel in the foundation or footing."
[291] See http://www.durisolbuild.com/Webdocs/Tech%20Guide%20(Photos).pdf.

2. (Above grade use ten-inch R-14 rockwool-insulated Durisol® wall forms. Use eight-inch or ten-inch R-8 uninsulated Durisol® wall forms above grade in hot climates.)

Choice Two (for added thermal performance):

1. Below grade use twelve-inch R-8 uninsulated or R-14 rockwool-insulated Durisol® wall forms.
2. (Above grade use twelve-inch R-20 or fourteen-inch R-28 rockwool-insulated Durisol® wall forms.)

Six- or eight-inch wall forms (which only come uninsulated) can be used for non-load bearing applications such as interior partition walls.

The ten-inch R-8 uninsulated wall forms suggested below grade as a foundation contain no rockwool and the entire 8½ inch hollow is filled with concrete and rebar. The ten-inch and twelve-inch R-14 wall forms both contain 1½ inches of rockwool and 7 inches of concrete. The twelve-inch R-20 and fourteen-inch R-28 wall forms each contain 3 inches of rockwool.

Below grade the ten-inch R-8 uninsulated wall form performs as well as 1½ inches of foam insulation, yet it is breathable. It also contains sufficient concrete and rebar within its core to be load bearing and provide structural stability for the entire house. Some clients choose to include the rockwool insert for additional insulation, though the company states it is not necessary in most applications.

Concrete block layers and masonry tradesmen can be easily shown how to construct low-density fiber-cement wall forms. Besides their comprehensive installation manuals, the manufacturers provide technical support to assist builders in all phases of installation.

We make the following additional recommendations:

1. If you are using the alternative infill protocol above-grade that is discussed in section 9.3, Alternative Protocol for Low-Density Fiber-Cement Wall Forms, you should fill all cavities of the Durisol® or Faswall® wall form in your foundation below grade with normal concrete and rebar, substituting fiberglass rebar for steel whenever possible for electrically sensitive clients.
2. If you are not using the alternative protocol above-grade, then follow the instructions provided in the Durisol® and Faswall® installation manuals.
3. **Very important:** When you pour concrete into the Durisol® foundation wall form cavities, do so in four foot passes; that is, keep moving around the building to fill the entire lower four feet and then return to the starting point after the concrete has begun to set. Follow instructions contained in the technical and installation manual provided by Durisol.[291]

4. If done properly the wall has enough friction to hold itself up. You do not need external forms except at corners, as recommended in the installation manual.
5. Install a capillary break over the footing. Use 6 to 10 mil plastic polyethylene or neoprene or an asphalt peel and stick product, applying the break between the footer and the wall.
6. Key out the footing to hold the bottom of the wall on the footing, so the wall itself does not slide during the back fill.
7. If there is a full basement, install perimeter footing drain tile of sufficient thickness to withstand the pressure of eight feet of backfill. Drain this to daylight or an external sump pump.
8. Apply a waterproofing material along the outside of foundation walls
    a. First apply a parge coating of three parts sand to one part Portland cement
    b. Next apply a layer of cementitious-based ThoroSeal®[292] waterproofing coating material
    c. Follow this with an air-gap drainage membrane such as the Delta®-MS and Delta-Drain®[289] or J-Drain®.[293] Place a screen along the top to let water evaporate but keep insects out.

(*Note*: No waterproofing material is necessary on a stem wall for a crawl space where the level of the ground inside the wall is lower than the outside soil level – see section 12.7.)

Additional considerations:

- Do *not* apply a pesticide and termite treatment such as Dursban® to the site soil.
- Treat all wood that is near the ground with a natural boricide to prevent termites and wood-boring insects. Apply this while the framing is accessible and not hidden by drywall or flooring.
- Install drain tile through footings angled downwards as you go from inside to outside, accessing the drain tile at the perimeter, one on each side. The slab level is higher inside than the drain tile outside.
- Install sturdy drain tile around outside of footings and bury in ASTM #5 aggregate covered with barrier cloth. Locate this drain tile at the level of the footing, below the level of the slab and higher than the bottom of the footing.
- Drain tile is to connect to daylight or to its own sump.

[292] Available from BASF Corporation: http://www.thoroproducts.com/products_waterproofing.htm.
[293] Available from JDR Enterprises (800-843-7569; www.j-drain.com).

17.5 Crawl Space

(See section 12.7 for a discussion of the rationale behind these protocols.)

- Use low-density cement-fiber wall forms or GreenKrete® or AAC blocks for stem wall foundation construction. Use a sand and concrete parge coating followed by Thoroseal® nontoxic breathable foundation waterproofer and a Delta®-MS or J-Drain® drainage membrane on the outside. This allows water to drain to French tile at the base of the foundation. *Note:* Only apply waterproofing and drainage membrane if inside ground level is below outside ground level.
- Provide cross-ventilation in excess of currently followed ventilation practices to allow much fuller airflow at all times, except in the coldest months of the winter (unless you are in a very hot climate). Include provisions to close off this ventilation if you experience colder winter months. This maintains crawl space temperatures in excess of deep soil temperatures, usually 55-60 ˚F below frost line, thereby avoiding condensation. You can and should open vents in warmer months from spring to autumn. Keep the air moving.
- If you place the HVAC system in the crawl space, this will help keep the crawl space temperature high enough in winter to avoid condensation (the air vents will be closed). Be sure the unit is accessible by the homeowner to easily and regularly change the furnace filter.
- Keep moisture out of the crawl space in heating season by sealing all air ducts at every seam with Mastic tape.
- For the same reason, seal all holes in the floor between the crawl space and the first-floor living space.
- Use cotton insulation wrap made by Superior Air Ducts (713-682-3828; www.superiorairducts.com) to insulate all air ducts in the crawl space, rather than fiberglass.
- Use cotton[294] rather than fiberglass batting at rim joists and under the sub-floor.
- Instead of covering the soil in the crawl space with heavy duty plastic and trying to seal it at the periphery, a better protocol is the following: First, prepare a milk-thin mix of 70% bentonite clay, 25% magnesia cement[295] and 5% borax and water and spray onto all exposed crawl space areas. Then powder the same dry mix about ¼ inch deep onto the leveled earth and lightly hose it with water to bleed into the soil.
- Provide a capillary break at the footing to avoid wicking of moisture up into the foundation and key out the footing as noted in the Foundation Protocol given above.

[294] Available from Bonded Logic (480-812-9114; www.bondedlogic.com).
[295] Bagged magnesia cement mixes are available from Grancrete (919-597-2500; www.grancrete.net) and from the Bindan Corporation (630-734-0277; www.bindan corp.com).

17.6 Finishing Within the Basement

Our profession does not recommend finishing a basement with a wood framed wall. Mold experts agree. In spite of efforts to seal up and contain moisture, the inevitable seepage or condensation cannot dry out, and mold growth behind finished basement walls is the result.

Instead, keep the walls exposed but finished with breathable, water-resistant finishes that allow moisture vapor to pass through but that keep water from blistering off paint. These were discussed in section 9.8, Breathable Waterproofing, Below Grade. The Xypex® breathable waterproofer and clay plaster are both tintable and can create as smooth a surface as wallboard. By not building a false wall, any moisture that accumulates on the wall can dry rapidly, and you always know the condition of your wall. Nothing is hidden.

These strategies work particularly well if you choose one of the thick wall materials presented in this manual as your foundation material, as all of them are breathable. Even if you choose a poured concrete foundation or concrete masonry units, we still recommend you use Thoroseal® and a dimpled drainage membrane, as this will help ensure a dry basement. Then apply Xypex® breathable waterproofer on the inside of the basement wall along with clay.

If you do choose to use to finish your basement, an air barrier can be built between the inner surface of the foundation and a stud wall. Be sure to apply Xypex® as a waterproofing finish on the inside of the foundation wall. If you use low-density cement-fiber wall forms, you will need a parge layer of sand and cement to create a smooth surface. Apply the Xypex® to that.

We would then recommend that studs be placed on 2x10 inch ACQ-treated sill plates to avoid wicking of any rising damp from the concrete floor to the wood, although this should not be a significant problem if wood chip pieces are laid under the slab. We suggest you spray the wood studs with the clay/magnesia/borate mixture mentioned above for the crawl space as well as in the alternative wood frame protocol in section 10.4.

We next suggest using dry cellulose or cotton batting as insulation rather than fiberglass, since both able to dry out more readily than fiberglass if they become damp. Again, this is much less likely to occur if any of the thick-wall materials are used as the foundation material, along with an air-gap membrane foundation wrap around the outside.

Remember, it is known that 90 to 95% of the time, mold growth in conventional basements can be avoided with proper rooftop rainwater management; that is, make sure that gutters and downspouts are present and in good working order, and that rainwater is drained well away from the foundation. Doing so will increase your chances that you will avoid a moldy basement, in this case from condensation and wicking through the wall, which is so common with conventional foundations.

We also recommend using dry cellulose or cotton batting as acoustical insulation in the basement ceiling, rather than blown-in fiberglass, and use cotton batting as insulation in the rim joists. This avoids loose fiberglass fibers from being drawn into the upstairs living space air via the "stack effect." We consider this to be an occupant health hazard as well as a potentially harmful influence for workers during installation.

Chapter 18. Above-Grade Envelope

18.1 Low-Density Fiber-Cement Wall Forms, Made with Portland Cement

The following protocol is provided by Durisol Building Systems. We recommend that you download and thoroughly review Durisol's Technical and Installation Guide.[296] *[In the final publication we intend to incorporate a similar protocol recommended by the K-X Faswall International Corporation. An updated Faswall® Technical Manual is available by contacting ShelterWorks. –Ed.]*

Choice One:

1. (Below grade use ten-inch R-8 uninsulated Durisol® wall forms (that is, uninsulated with rockwool insert).)
2. Above grade use ten-inch R-14 rockwool-insulated Durisol® wall forms. Use eight-inch or ten-inch R-8 uninsulated Durisol® wall forms above grade in hot climates.

Choice Two (for added thermal performance):

1. (Below grade use twelve-inch R-8 uninsulated or R-14 rockwool-insulated Durisol® wall forms.)
2. Above grade use twelve-inch R-20 or fourteen-inch R-28 rockwool-insulated Durisol® wall forms.

Six- or eight-inch wall forms (which only come uninsulated) can be used for non-load bearing applications such as interior partition walls.

The ten-inch R-8 uninsulated wall forms contain no rockwool and the entire 8½ inch hollow is filled with concrete and rebar. The ten-inch and twelve-inch R-14 wall forms both contain 1½ inches of rockwool and 7 inches of concrete. The twelve-inch R-20 and fourteen-inch R-28 wall forms each contain 3 inches of rockwool.

Concrete block layers and masonry tradesmen can be easily shown how to construct low-density fiber-cement wall forms. Besides their comprehensive installation manuals, the manufacturers provide technical support to assist builders in all phases of installation.

In both cases high quality doors and low-E windows need to be used to achieve optimal effective R-values in the field.

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[296] See http://www.durisolbuild.com/Webdocs/Tech%20Guide%20(Photos).pdf.

Very important: When you pour concrete into the Durisol® foundation wall form cavities, do so in four foot passes; that is, keep moving around the building to fill the entire lower four feet and then return to the starting point after the concrete has begun to set. Follow instructions contained in the technical and installation manual provided by Durisol Building Systems.[296]

If done properly the wall has enough friction to hold itself up. You do not need external forms except at corners, as recommended in the installation manual.

Building biologists recommend using fiberglass rather than steel rebar whenever possible for electromagnetic reasons, as discussed above in Alternatives to Steel Rebar. A promising development is the use of basalt as rebar, already in use in Eastern Europe.

If you purchase Faswall® wall forms from ShelterWorks, be sure to specify that you do not want fly ash mixed with the Portland cement portion of the form because fly ash contains traces of toxic chemicals from burning coal. This topic is discussed in section 8.8. Durisol does not put fly ash into its wall forms.

Here is Durisol's protocol for attaching strapping and cladding to their wall forms"

1. Build the Durisol® wall.
2. Before pouring the concrete, place the strapping against the wall with screws protruding into empty cavity. This way, when the concrete is poured, it will embed the screws in concrete and the strapping then becomes securely fastened to the concrete core. Alternately, you can attach the strapping to the wall after the concrete is poured, using Tapcon® concrete anchors. Either way, it is recommended that the strapping is attached to the concrete core and not just Durisol® (low-density fiber-cement jacket).
3. Parge the wall, in between the lines of strapping. This will provide a very good air barrier.
4. Attach siding to the strapping.

Durisol Building Systems also recommends Simpson® NSP 2 Nail Stop anchor plates[297] to attach siding. The attaching of siding, masonry and stone cladding is covered in detail in the company's Installer's Guide.[296]

18.2 Low-Density Fiber-Cement, Made with Alternative Cement

GreenBlok®, made by GreenKrete® Building Systems in Fairfield, Iowa (866-306-0939, www.greenkrete.com), is a solid masonry block erected with thin-set mortar. They are used below and above grade and can be reinforced for construction greater than three stories. They require no additional reinforcement

[297] Manufactured by the Simpson Strong-Tie Company Inc.(www.strongtie.com).

up to that height. GreenBloks are an excellent substrate for stucco and plaster. GreenKrete® is discussed in section 8.10.

The company provides technical data and support to trades people new to their product. The company can also be contracted to provide on-site construction supervision of your project if it is located within the mid-West.

18.3 Autoclaved Aerated Concrete (AAC)

AAC is constructed with polymer-modified thin-set mortar provided by the manufacturer.

Rebar is used at corners and around all windows and doors.

Rebar is required at corners and around openings in accordance with ICC Evaluation Report 1371. This and other installation details are provided by each manufacturer on their website, where you can locate technical guides as well as ASTM and other testing data.

Plumbing and electrical lines are installed in chases that are easily routed or sawn in the block. These are then patched with mortar or foam. (Nontoxic brands are available from green building retailers.)

Roof trusses are attached to using a top plate, anchor or ledges.[251] J-bolts placed at the side of the bond beam block are used to attach the ledgers with 4 inches of concrete filled around the anchor bolt to the face of the wall.

For further details see the technical manuals and installation guides provided by each manufacturer.

18.4 Magnesia-Based Sheeting

As discussed in section 10.3, magnesia-based sheets can be used for multiple purposes on the job site in place of manufactured wood or gypsum-based products. Please refer to that section for details on its use.

This includes sheathing, drywall, subfloors and roof decking. One particular application as an alternative to the traditional wood-frame wall is presented below.

18.5 Alternative Wood-Frame with MgO Board

See chapter 10 for the rationale behind this alternative protocol to standard wood-frame construction.

The protocol involves the following steps:

1. Spray the wood frame with a thin layer of magnesium phosphate, kaolin clay and borate.
2. Embed any stud-to-concrete framing in a thick preserving bed of magnesium oxide and clay.
3. Install magnesium boards on the outside of the wood frame as sheathing.
4. Fill the cavity with cotton insulation, which has the capacity to dry out through the breathable MgO boards inside and out. An alternative to cotton is to spray a mixture of wet magnesium oxide, clay and borax along with cellulose into the cavity.
5. Install magnesium boards on the inside of the wood frame in place of drywall.
6. The inner wall is finished with natural plaster, and the exterior with mineral stucco paint, discussed below.

The ratio of magnesium to clay should be as follows: Blend 30% magnesium phosphate with 68% bentonite or kaolin clay, and add 2% borax (essentially one third magnesia-based cement to two thirds clay with a pinch of borax).

For exterior applications the sheets can be stuccoed directly with an ultra-thin single layer of all-natural mineral-based stucco paint. You can also skillfully apply a single coat of magnesium phosphate and sand stucco, mixed on site, directly over fiberglass-seamed joints. This greatly reduces steps and costs in traditional construction.

18.6 Finishes, Interior and Exterior, for Thick-Wall Envelopes

We recommend breathable stucco and mineral paints, covered with an additional breathable waterproofer, Miracle Cover®. Several brands of breathable stucco, based upon magnesium, were discussed in sections 8.9and 9.7. These include:

- Substance Distributing Co. in Austin, Texas (512-385-4326; www.substanceproducts.com)
- Bindan in Chicago (630-734-0277; www.bindancorp.com)
- Grancrete in North Carolina (919-597-2500; www.grancrete.net)
- CeraTech in Virginia (800-581-8397; www.ceratechinc.com)

We also list several domestic manufacturers or importers of mineral stucco paint. These include:

- Keim Mineral Coatings of America, Inc., Charlotte, North Carolina (866-906-5346; 704-588-4811; www.keim.com)

- Edison Coatings in Plainville, Connecticut (800-697-8055; www.edisoncoatings.com)
- Silacote, with offices throughout the country (800-766-3157; www.silacote.com)
- Eco-House, Inc. of Fredericton, New Brunswick (877-326-4687; www .eco-house.com)

Miracle Cover® is available at 800-304-7325; www.miraclecoverinc.com.

In wetter climates with wind-driven rain, one can add a base coat of three parts sand to one part Portland cement, and/or a layer of cement-based Thoroseal (952-496-6000; http://www.thoroproducts.com/products_waterproofing.htm).

18.7 Roofing

[Construction protocols for roofing will be included in the next edition. Please refer to chapter 13 for detailed information on this topic. –Ed.]

Part Four. CONCLUSION

We have attempted to provide you with a detailed road map to a better outcome than most builders and homeowners have experienced in the past few decades. As you read these pages you likely have come to the realization that, in order to solve the current problem of sick buildings resulting from water intrusion, mold, and our drive to create tight, energy-efficient buildings without compromising indoor air quality, we must borrow from the past to recreate solid, durable, sustainable buildings that keep us healthy and have minimal impact on the environment. Post and beam construction, natural fiber and cement, and thick walls are just some of the techniques our ancestors used that have stood the test of time. As with society's adventures in modern medicine, where we have lost sight of how the body creates wellness, we have likewise strayed into a habit of ever-tightening walls with plastic, creating the very problem we are trying to solve. Alternative approaches in medicine appear new but are in reality a return to traditions abandoned decades ago that had successfully kept civilizations healthy for centuries, if not millennia.

Yes, you will pay more for natural, breathable, massive building materials. But when you choose them, you build a home worth living in for decades that will keep you healthy and that pays for itself over time. You truly get what you pay for.

We have attempted in this manual to stay true to the principles and ideals of our Building Biology® profession, particularly as taught by its founders in Germany and in this country by our Institute's founder, architect Helmut Ziehe. He, his wife, and the early members of our profession have been our guiding light in following the ways of Helmut's native land, where buildings still stand today, centuries after they were first constructed, and the population generally enjoys good health in their homes.

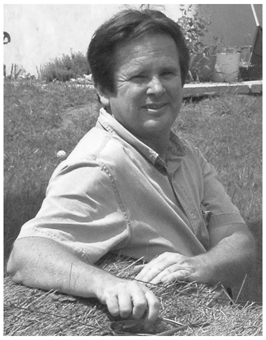
We don't expect all builders and homeowners to adopt our approaches. They are not for everyone. Too much time, attention and money needs to be spent for some in the trade. Yet for those who do take the time and effort to learn what we have to offer and to incorporate these techniques and materials into your plans, you will be richly rewarded with a home that provides good health, durability, comfort and the ability to handle whatever may come with changes in weather patterns and higher energy prices.

We again thank the many individuals who have helped us bring out this knowledge, and welcome your feedback as we endeavor to make this manual more informative and user-friendly for you, our reader.

The best of luck to you.

George Swanson, Oram Miller, and Wayne Federer

About the Contributors



George Swanson received a Bachelor of Science in Industrial Technology from Western Washington University in June 1975. Since that time he has worked throughout the Pacific Northwest, the Great Plains, and the Southeastern United States, designing, building, and managing construction of homes and commercial buildings. His popular *Dome Scrap Book*, inspired by the works of Buckminster Fuller and published in 1981, distills George's experiences designing and participating in building more than 300 geodesic dome structures in the Pacific Northwest from 1974 to 1981.

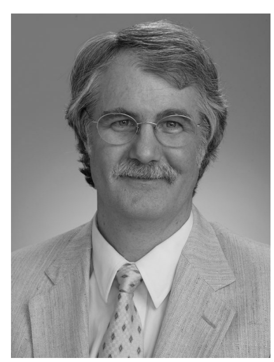
Since the 1980's George's firm, Swanson Associates, now based in Austin, Texas, has completed nearly one hundred low-toxic and fully nontoxic "breathing" natural building projects in eleven states and several foreign countries. Some of the building systems used were traditional straw-clay, rammed earth, Faswall® cement-bonded wood fiber wall forms, autoclaved aerated concrete block, and most recently magnesia-based (MgO) natural ceramic cement. Several of these projects have included single-family wetland septic systems, rooftop water collection systems, pervious concrete landscape features and solar voltaic energy systems.

George graduated in 1992 from the International Institute for Bau-biologie® and Ecology (IBE) as a Building Biology® Practitioner and was listed in *Who's Who in America* in 1996 for his contributions to Sustainable Technology. Currently he offers natural home and commercial building consulting, design and construction oversee services throughout the states and abroad.

In recent years Swanson Associates have been lead design/build consultants for numerous commercial projects, including several churches, a monastery and a twenty-one-building natural medicine complex in Austin, Texas. Ongoing long-term international projects include a waterfront eco-resort in Kauai, restoration of an ancient hacienda in Mexico, and an eco-village complex in Trinidad. Recently George returned from his fourth trip to China where on an ongoing basis he is conducting product development for DragonBoard®, including all-natural fiber/MgO cement-based wall, roof and floor prefabricated structural insulative panels (SIP's). He is also a partner in the Substance Distributing Company of Austin which distributes several brands of MgO-based building materials.

Since 1975 George has conducted hundreds of seminars across the country and abroad on the benefits of natural building design. He can be contacted at 512-653-8624 or gps@flash.net, or via his website, www.geoswan.com.

Oram Miller is based in Minneapolis, Minnesota where he provides healthy home and office evaluations to clients on site throughout the upper Midwest and nationwide by telephone, fax and email.



Following his education at Colby College (Bachelor of Arts in Biology, 1971) and a 23-year career as a health care practitioner, in December 2003 Oram received his certification as a Building Biology® Environmental Inspector (BBEI) from the International Institute for Bau-biologie® and Ecology. His training included assessment and mitigation of unhealthy electric and magnetic field exposure, indoor air quality, mold, and chemical outgassing.

In addition to helping clients with the latter concerns, Oram consults on the design, building and remodeling of healthy homes and offices in Minnesota and throughout the country. Besides wall and foundation materials as taught by George Swanson, Oram recommends a healthy electrical wiring protocol to create reduced EMF (electromagnetic field) exposure.

Oram writes and lectures on health and the built environment. He has presented to the University of Minnesota, the Minnesota Chapter of the American Institute of Architects (AIA), the National Association of the Remodeling Industry (NARI), the Living Green Expo and the Eco-Experience at the Minnesota State Fair, and the annual conference of the International Institute for Bau-biologie® and Ecology. He has also spoken at numerous healthy living expos and green building meetings.

Oram is active in several organizations dedicated to green construction. These include the Mississippi Headwaters Chapter of the U.S. Green Building Council , the Minnesota Chapter of the American Institute of Architects, and the Minnesota ASHRAE Sustainable Design Committee. He also moderates a monthly study group called the Midwest Building Ecology Coalition.

Lastly, Oram was asked to submit a healthy electrical wiring protocol to the Minnesota GreenStar Program, and he is now a member of their Technical Committee. The protocol is based upon guidelines developed by Oram's colleague and mentor, Spark Burmaster, EE, BBEI of Chaseburg, Wisconsin.

Please contact Oram at Environmental Design and Inspection Services (952-412-0781 or info@createhealthyhomes.com) and visit his website, www.createhealthyhomes.com.

Wayne Federer is based in rural northwestern Wisconsin, on the outskirts of Minnesota's Twin Cites metro area. In 1977 he received Bachelor's and Master's degrees in Chemistry from Bucknell University and went on to the University of Illinois to complete a Ph.D. program in Inorganic Chemistry in 1984.

While still in school, Wayne was inspired to became an environmentalist by his love of the outdoors and his reading of Rachel Carson's *Silent Spring*. However because he has always enjoyed research, Wayne joined the corporate world as a scientist, taking every opportunity he could to foster an environmental ethic. In his 14-year industrial career investigating advanced magnetic and ceramic materials, he gravitated towards projects addressing environmental concerns, including catalytic purification and filtration of indoor air and diesel emissions. In 1989 Wayne was a leader in the organization of a company-wide conference and movement to motivate employees to integrate consideration of environmental concerns into product and process design from the moment of each product's conception. In his community he has advocated for intelligent land-use planning and conservation design of subdivisions.

After striking out on his own, Wayne proceeded to study Building Biology® with the IBE class of 1998. He has attended green building workshops and independently researched many health and environmental issues since then. For this manual, his first foray into the world of editing, he has contributed his scientific and critical thinking skills. The latter are most evident in his writing of chapter 6, for which he gathered input about "breathing walls" from our international colleagues.

Although Wayne's favorite abode is a tent in the wilderness, most of the time he lives in a conventionally-built 1973 rambler. He welcomes your email to editor@breathingwalls.com.

Ordering Information (multiple formats and updates)

Breathing Walls: A Biological Approach to Healthy Building Envelope Design and Construction, © 2008 by George P. Swanson, Oram Miller, and Wayne D. Federer, may be ordered directly from the website dedicated to this book, **www.breathingwalls.com**. An alternate route to our secure e-commerce server is via links from the authors' websites, www.geoswan.com and www.createhealthyhomes.com.

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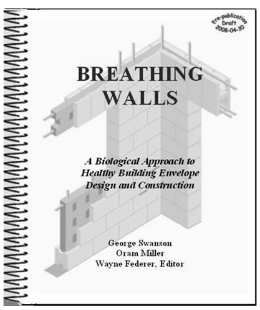
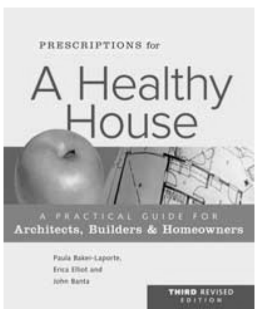
Breathing Walls: A Biological Approach to Healthy Building Envelope Design and Construction
by George Swanson, Oram Miller and Wayne Federer, Editor
Spiral bound and eBook, 304 pages (Pre-publication draft, April 2008); <http://www.breathingwalls.com>



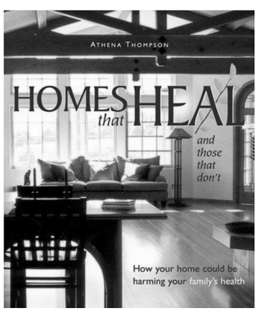
Breathing Walls offers practical alternatives to conventional modern building practices that keep homes airtight. Walls built today are energy-efficient but cannot handle the inevitable intrusion of moisture, resulting in mold, ill health for occupants and structural damage. Healthy, nontoxic alternatives are provided for building walls, foundations, slabs and roofs that allow moisture to dry out before mold can grow while saving energy. Contractor-friendly choices include various thick, "breathable" materials (low-density fiber-cement wall forms or blocks, autoclaved aerated concrete, and wood log) as well as a thin-wall option that employs magnesia-based boards, a material extensively used in Asia. Detailed protocols explain the application of these materials on the job site. Written by building biologists, this is a helpful reference manual for builders, architects and homeowners wanting to build green *and* healthy.

Also Authored by Building Biologists



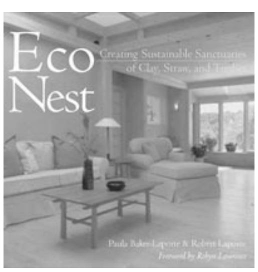
Prescriptions for A Healthy House, 3rd Edition: A Practical Guide for Architects, Builders & Homeowners by Paula Baker-Laporte, John Banta and Erica Elliot; paperback, 336 pages (New Society Publishers, May 2008); <http://www.newsociety.com/bookid/3997>

"From foundation to rooftop, to home care and repair, *Prescriptions for a Healthy House* takes the mystery out of healthy-house building, renovation and maintenance, by walking the owner/architect/builder team through the entire construction process. Chapters include: Frame construction alternatives, Thermal and moisture control, Finishes, Flooring and Furnishings. Written by an architect, medical doctor and restoration consultant, the book provides a unique guide to creating healthy indoor and outdoor spaces, including many new resources, as well as specialized knowledge from several nationally recognized experts in the field of building biology®."



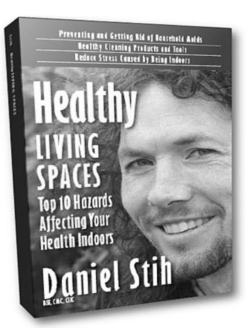
Homes That Heal and Those that Don't: How Your Home Could Be Harming Your Family's Health by Athena Thompson; paperback, 320 pages (New Society Publishers, October 2004); <http://www.homesthatheal.com>

"*Homes that Heal* is a passionate examination of our built environment and the alarming impact today's chemically polluted world is having on our children's health and future generations. Athena explains how our homes influence our health and what we can do about it. The reader is empowered with solutions that reduce the chemical load on all of us while helping create natural, ecologically sound living environments that nurture human health."



Eco Nest - Creating Sustainable Sanctuaries of Clay, Straw, and Timber by Paula Baker-Laporte and Robert Laporte; paperback, 128 pages (Gibbs Smith, Publisher, September 2005); <http://www.econest.com>

"*EcoNest* identifies homes designed and built respectfully, in appreciation of the harmony and beauty of nature and in a way that uses nature's resources so as to consume less energy, create less waste, nurture our health, and enrich our senses. A bird builds its nest using the materials at hand to create a perfect shelter for its bioregion. It doesn't fly to the next state for twigs nor does it build a home that is bigger than it needs. Instinctively it creates an environment that is nurturing, nontoxic, and free of synthetic chemicals. Like the bird, humans desire shelter that is cozy and nurturing, that satisfies the soul, mind, and body. This is the econest."



Healthy Living Spaces – Top 10 Hazards Affecting Your Health by Daniel Stih; paperback, 120 pages (Healthy Living Spaces, June 2007); <http://www.hlspaces.com/HLSBook.htm>

"We may feel it's difficult to create a healthy home. Fortunately, ninety-percent of indoor-health issues can be avoided by focusing on the Top 10. Each item on the Top 10 list is covered in a separate chapter explaining: What is it, what can it do to me, where is it and how do I get rid of it? The first chapter covers all aspects of dealing with mold. The book makes common-sense suggestions for creating a safe, allergy-free environment that include: Getting rid of mold safely and effectively, buying or building a mold-free home, reducing stress caused by indoor toxins, and recommended cleaning products, vacuum cleaners, and air filters."