CLL251: HEAT TRANSFER FOR CHEMICAL ENGINEER

Thermal Analysis of Passive Solar Cooling Systems and Passive House Design Strategies

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Abstract:

Passive design responds to local climate and site conditions in order to maximise the comfort and health of building users while minimising energy use. The key to designing a passive building is to take best advantage of the local climate. Passive cooling refers to any technologies or design features adopted to reduce the temperature of buildings without the need for power consumption. Consequently, the aim of this study is to test the usefulness of applying selected passive cooling strategies to improve thermal performance and to reduce energy consumption of residential buildings in hot arid climate settings, namely Dubai, United Arab Emirates. One case building was selected and eight passive cooling strategies were applied. Energy simulation software – namely IES – was used to assess the performance of the building. Solar shading performance was also assessed using Sun Cast Analysis, as a part of the IES software. Energy reduction was achieved due to both the harnessing of natural ventilation and the minimising of heat gain in line with applying good shading devices alongside the use of double glazing. Additionally, green roofing proved its potential by acting as an effective roof insulation. The study revealed several significant findings including that the total annual energy consumption of a residential building in Dubai may be reduced by up to 23.6% when a building uses passive cooling strategies.

Introduction

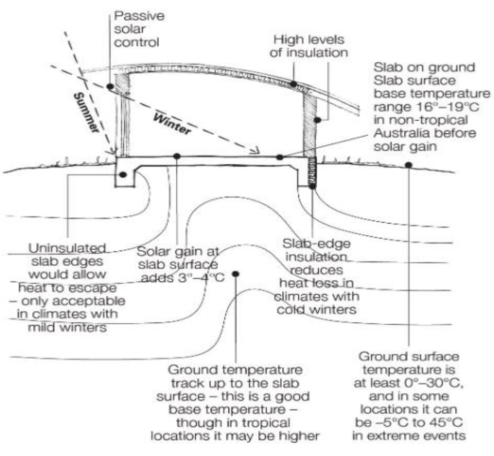
Imagine a world where our homes and buildings work harmoniously with nature, keeping us comfortable while reducing our environmental footprint. This project embarks on that journey, exploring the fascinating realm of passive solar cooling systems and passive house design strategies. We're diving deep into how these innovative approaches not only keep spaces cool in a sustainable manner but also pave the way for greener, more energy-efficient living. Our plan is to uncover the secrets behind their success, from the design blueprints to the materials used, and to present a comprehensive thesis on their impact on thermal comfort, energy savings, and environmental friendliness. This report is not just about buildings; it's about reimagining our relationship with the spaces we inhabit, making them healthier and more sustainable for generations to come.

Experimental Methods

Earth Coupling:

Ground and soil temperatures vary throughout Australia. Earth coupling is where concrete floors (and sometimes walls) are in direct contact with the earth. In a well-insulated properly shaded house, this ‘draws up’ the stable deeper ground temperatures to the surface of the floor, which gives the house a head start in regulating temperature.

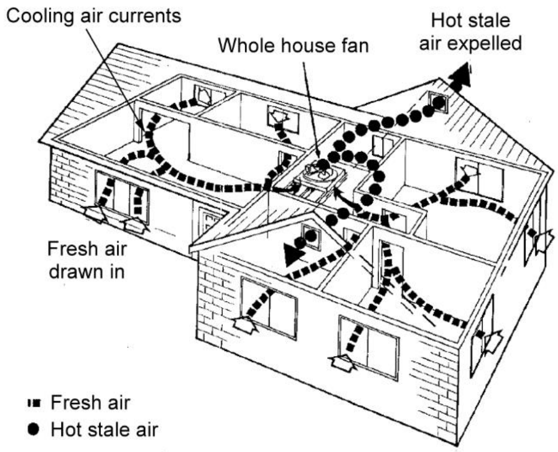
Earth-coupled concrete slabs-on-ground are effective for passive cooling where deep earth temperatures (at a depth of 3 metres or more) are low, such as in most of southern Australia. This strategy should be avoided in climates where deep earth temperatures contribute to heat gain, such as in most northerly latitudes where suitable ground temperatures do not occur at useful depths. In these regions, use open vented floors with high levels of insulation to avoid heat gain. Obtain expert building design advice to determine deep ground temperatures.



Whole of house of fans:

A whole-of-house fan is a single fan unit installed in a circulation space in the centre of the house (hallway or stairwell) to draw cooler outside air into the building through open windows and out through the roof space. It exhausts the warm air through eaves, ceiling or gable vents. This also helps to cool the roof space and reduces any temperature differential across ceiling insulation.

Whole-of-house or roof fans are good for cooling buildings, particularly where cross-ventilation design is inadequate. They do this by exchanging all of the air in the house many times every hour, assuming there is sufficiently cool outside air to provide cooling. However, they do not create sufficient air speed to cool people.

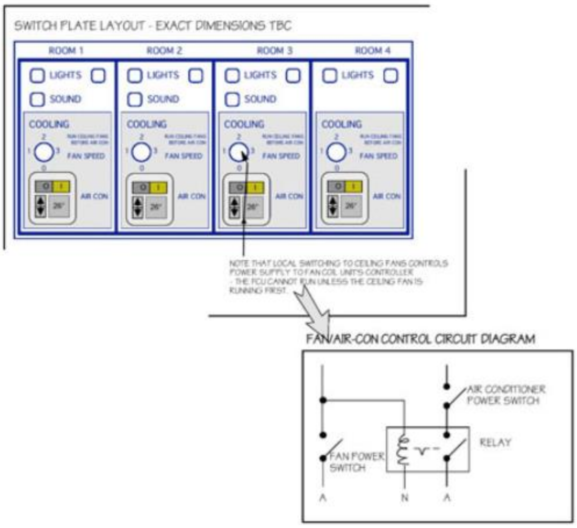


Whole-of-house fans can be noisy at full speed but are generally operated in the early evening when cooling needs peak and households are most active. If run at a lower speed throughout the night, they can draw cool night air across beds that are near open windows, provided doors are left open for circulation. On still nights, this can be more effective than air-conditioning for night-time sleeping comfort.

These systems are used when external temperatures are lower than internal temperatures and should have controls to prevent the fan operating when external air temperatures are higher than internal. These systems work well as long as all openings are air-tight in cooler seasons. Drawing large volumes of humid air through the roof space can also increase condensation, therefore this should be considered when specifying and installing insulation.

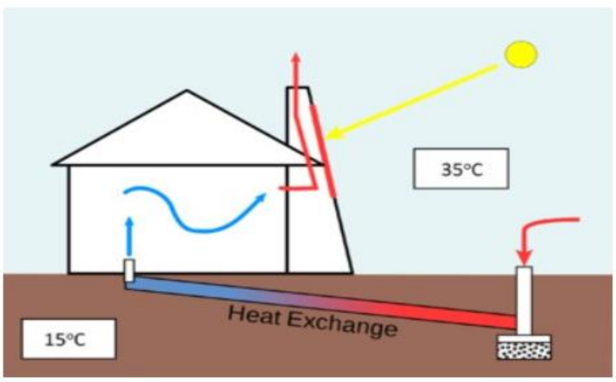
Hybrid cooling systems:

Hybrid cooling systems are whole-house cooling solutions that use a combination of cooling options (including air-conditioning) in the most efficient and effective way. They take maximum advantage of passive cooling when available and make efficient use of mechanical cooling systems during extreme periods. For example, running an air-conditioner in a closed room for about an hour at bedtime often lowers humidity levels to the point where air movement from ceiling fans can provide sufficient evaporative cooling to achieve and maintain sleeping comfort. Clever electrical design using master circuits or solenoids can be used to ensure the fans are running before power is available to the air-conditioning.



Hybrid cooling solutions require a decision early in the design stages about whether air-conditioning is to be used and how many rooms require it. Inefficient air-conditioning installations can occur when they are added to a home designed for natural cooling as an afterthought.

Solar Chimneys: Solar chimneys can be a passive form of cooling for a home. In a solar chimney, a tall chimney is placed to be heated by the sun. This heats air within the chimney and causes it to rise. This draws in air from the rest of the house, which in turn draws in air from the outside or from underground pipes.

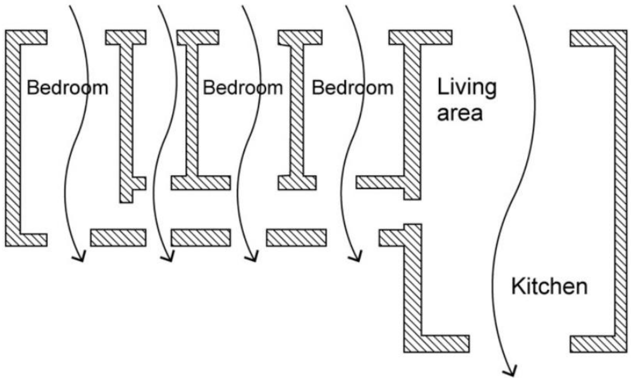


Cool Breezes:

Where the climate provides cooling breezes, maximizing their flow through a home is a key component of passive cooling.

Cool breezes work best in narrow or open-plan layouts and rely on air-pressure differentials caused by wind or breezes. They are most effective in:

- buildings with narrow floor plans or open-plan layouts
- locations without long periods of high external temperature (ambient or conducted heat gains above 35–40 watts per square meter)
- locations where windows can be left open (that is, secure, quiet locations with good outdoor air quality).



Discussions

Passive solar design takes advantage of a building's site, climate, and materials to minimize energy use. A well-designed passive solar home first reduces heating and cooling loads through energy-efficiency strategies and then meets those reduced loads in whole or part with solar energy. Because of the small heating loads of modern homes, it is very important to avoid oversizing south-facing glass and ensure that south-facing glass is properly shaded to prevent overheating and increased cooling loads in the spring and fall.

Energy efficient first:
Before you add solar features to your new home design or existing house, remember that energy efficiency is the most cost-effective strategy for reducing heating and cooling bills. Choose building professionals experienced in energy-efficient house design and construction and work with them to optimize your home's energy efficiency. If you're remodeling an existing home, the first step is to have a home energy audit to prioritize the most cost-effective energy efficiency improvements**.**

Site selection:
If you're planning a new passive solar home, a portion of the south side of your house must have an unobstructed "view" of the sun. Consider possible future uses of the land to the south of your site—small trees become tall trees, and a future multi-story building can block your home's access to the sun. In some areas, zoning or other land use regulations protect landowners' solar access. If solar access isn't protected in your region, look for a lot that is deep from north to south and place the house on the north end of the lot.

How passive cooling design cooling works:

A passive solar home collects heat as the sun shines through south-facing windows and retains it in materials that store heat, known as thermal mass. The share of the home's heating load that the passive solar design can meet is called the passive solar fraction, and depends on the area of glazing and the amount of thermal mass. The ideal ratio of thermal mass to glazing varies by climate. Well-designed passive solar homes also provide daylight all year and comfort during the cooling season through the use of nighttime ventilation**.**

To be successful, a passive solar home design must include some basic elements that work together:

- **Properly oriented windows**. Typically, windows or other devices that collect solar energy should face within 30 degrees of true south and should not be shaded during the heating season by other buildings or trees from 9 a.m. to 3 p.m. each day. During the spring, fall, and cooling season, the windows should be shaded to avoid overheating. Be sure to keep window glass clean.

- **Thermal mass**. Thermal mass in a passive solar home -- commonly concrete, brick, stone, and tile -- absorbs heat from sunlight during the heating season and absorbs heat from warm air in the house during the cooling season. Other thermal mass materials such as water and phase change products are more efficient at storing heat, but masonry has the advantage of doing double duty as a structural and/or finish material. In well-insulated homes in moderate climates, the thermal mass inherent in-home furnishings and drywall may be sufficient, eliminating the need for additional thermal storage materials. Make sure that objects do not block sunlight on thermal mass materials.

- **Distribution mechanisms.** Solar heat is transferred from where it is collected and stored to different areas of the house by conduction, convection, and radiation. In some homes, small fans and blowers help distribute heat. Conduction occurs when heat moves between two objects that are in direct contact with each other, such as when a sun-heated floor warms your bare feet. Convection is heat transfer through a fluid such as air or water, and passive solar homes often use convection to move air from warmer areas -- a sunspace, for example -- into the rest of the house. Radiation is what you feel when you stand next to a wood stove or a sunny window and feel its warmth on your skin. Darker colors absorb more heat than lighter colors, and are a better choice for thermal mass in passive solar homes.

- **Control strategies**. Properly sized roof overhangs can provide shade to vertical south windows during summer months. Other control approaches include electronic sensing devices, such as a differential thermostat that signals a fan to turn on; operable vents and dampers that allow or restrict heat flow; low-emissivity blinds; operable insulating shutters; and awnings.

Refining the design:

Although conceptually simple, a successful passive solar home requires that a number of details and variables come into balance. An experienced designer can use a computer model to simulate the details of a passive solar home in different configurations until the design fits the site as well as the owner's budget, aesthetic preferences, and performance requirements**.**

Some of the elements the designer will consider include: Fabrication and optimization of free-standing perfusable tissue constructs

- Insulation and air sealing
- Window location, glazing type, and window shading
- Thermal mass location and type.
- Auxiliary heating and cooling systems.

Conclusions:

In the culmination of this exploration, we stand at the crossroads of science and humanity, where the art of sustainable living meets the precision of scientific inquiry. Through the lens of Computational Fluid Dynamics (CFD), dynamic thermal simulation, energy modeling, daylighting analysis, and life cycle assessment (LCA), we've unraveled the tapestry of passive solar cooling systems and passive house design strategies, revealing their transformative potential in shaping our built environment and enriching our lives.

Our journey began with the whispers of air and heat, as CFD simulations painted a vivid portrait of airflow melodies and thermal harmonies within our architectural canvas. These simulations, akin to digital maestros, orchestrated a symphony of comfort, where cool currents and gentle breezes embraced us, guided by nature-inspired design elements and mindful energy conservation.

Through the lens of dynamic thermal simulations, we witnessed the ebb and flow of thermal energies, from the warm embrace of sunlight to the cool caress of shaded retreats. This dance of warmth and comfort, choreographed by passive design strategies and thermal resilience, painted a picture of sustainable coziness, where buildings adapt seamlessly to nature's rhythms.

Energy modeling emerged as our compass in the quest for efficiency, navigating the intricate terrain of energy flows, demand profiles, and renewable potentials. Like skilled navigators, we charted courses towards energy savings and carbon footprint reductions, weaving together passive strategies, renewable energies, and operational optimizations into a tapestry of sustainable abundance.

Daylighting analysis illuminated our spaces with the magic of natural light, casting shadows of comfort and warmth, while reducing our reliance on artificial luminescence. This dance of light and shadow, guided by design ingenuity and human-centric principles, fostered spaces that breathed with life and vitality. And as we peered through the lens of life cycle assessment (LCA), we embraced the holistic narrative of sustainability, tracing the environmental footprints of our architectural choices from inception to legacy. With each material decision, operational practice, and design intervention, we nurtured ecosystems, minimized waste, and embraced regenerative paradigms.

In conclusion, our scientific odyssey unveils not just buildings but habitats that resonate with life, comfort, and sustainability. It's a testament to our collective journey towards a future where science and humanity intertwine, crafting spaces that nourish the soul, conserve resources, and inspire generations to come.

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Appendices:

Adapting lifestyle' means adopting living, sleeping, cooking and activity patterns that respond to, and work with, the climate rather than using mechanical cooling to emulate an alternative climate.

Lifestyle adaptions can be a significant factor in achieving thermal comfort:

- Acclimatise your body to slightly warmer temperatures. If using air-conditioning, adjust your thermostat to between 25°C and 27°C – each degree cooler will increase your energy needs by 10%.
- Vary active hours to make best use of comfortable temperature ranges at different times of the year (for example, do outside work in the early morning).
- Live outside when time of day and seasonal conditions are suitable — particularly in the cooler evenings.
- Cook outside (for example, on barbeques) during hotter months to reduce heat loads from cooking inside.

Verandas, underfloor ventilation, shady plantings and ceiling fans keep this classic Darwin home comfortable in tropical heat