THE POTENTIAL OF ENERGY CONSERVATION IN BUILDINGS

Devang Chauhan cdev@design.upenn.edu
Christopher Colgan Colgan@design.upenn.edu
Katelyn Mulry kmulry@design.upenn.edu

Advisor: **Noam Lior**, Ph.D.
Professor of Mechanical Engineering and Applied Mechanics
School of Engineering and Applied Science
University of Pennsylvania

Last Updated on: 11th December, 2012

1. INTRODUCTION

Buildings worldwide account for a surprisingly high 40% of global energy consumption, and the resulting carbon footprint, significantly exceeding those of all transportation combined. Large and attractive opportunities exist for energy conservation in building sector higher returns than other sectors. This conservation is fundamental to reduction in the planet's carbon footprint to reach stabilized CO2 levels to which construction industry contributes significantly.

At the same time, substantial work and efforts will be required to achieve this target. These will require the combination of actions called for in this report, including building energy codes, investment subsidies, labeling and reporting mechanisms, increased and trained workforce capacity, and evolving energy-efficiency designs and technologies. All are intended to raise energy awareness globally and influence consumer and investor behavior and choice.

We value human life to an extraordinary degree and have put in place building life safety codes and inspection mechanisms over a century or more. Such codes are best accomplished through collaboration between governments and the building sector, with governments providing regulatory oversight, enforcement and financial support for passive designs, active technologies and disciplines proposed by business. Although strong barriers exist in the building sector. Removing them will reduce climate policy costs overall and will be particularly important in alleviating the impact on consumers.

This is a challenging time to be considering cost increases for anything. On the other hand, many energy conservation projects for buildings offer attractive financial returns. It is also clear that delaying action will only increase the ultimate CO2 reductions and associated costs needed for climate stability. We are in a world where buildings' energy efficiency is critically important to address climate change and it is by the concerted actions of the nations that world can change the approach towards energy use in buildings for the betterment of posterity.

2. BACKGROUND REVIEW

The analysis and research work of global organizations such as; WBCSD and IEA provides in depth review of the existing energy consumption in building sector for the world and some of the developed countries. These organizations, along with other organizations of similar intend, have been developing pattern studies for energy consumption in building sector and based on those patterns they have also determined the barriers to the development and adoption of energy conservation in building industry of a particular country and world. The work of such global organizations also offers tangible solutions to improve the energy conservation and the adoption of relevant concepts in society. However, the need for quantitative information regarding energy conservation in building sector remains to be addressed globally by national organizations of relevant countries.

3. SCOPE OF RESEARCH

This section of the paper takes a critical look at the existing energy conservation practices around the world and for one country in specific (India) in order to analyze the potential of energy conservation in building industry.

4. METHOD OF RESEARCH

A critical analysis has been conducted for energy conservation attempts and practices around the world and for a country (India). In order to understand the development and adoption this concept of energy conservation, the existing building industry standards, rating systems, and energy consumption data has been analyzed for the world and for India in order to meet the objective of the research.

5. RESEARCH

5A1. Critical analysis of Energy Conservation in Buildings throughout the world.

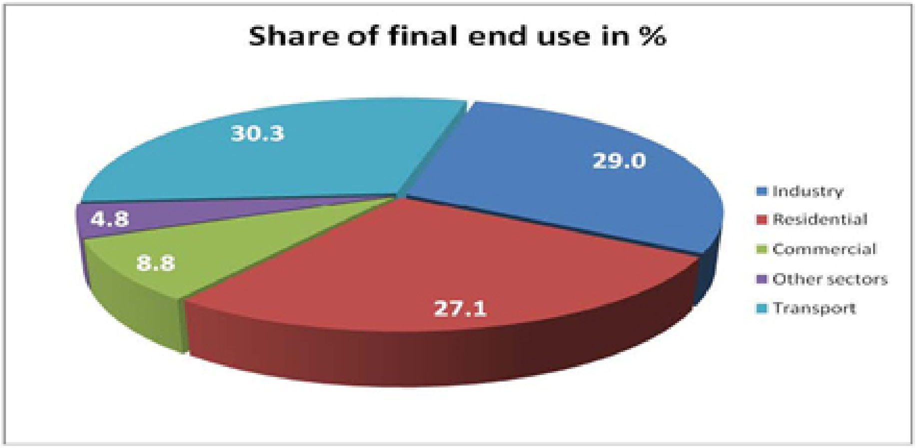
In today's world, many estimates of the results of the possible energy conservation in buildings exist and although the results usually vary, there is general agreement that the untapped potential for energy conservation in buildings is significant. Along with saving both energy and money, wider use of efficient technologies can address multiple environmental concerns, offset the need for additional electricity generating capacity, and reduce dependence on cost intensive and environmentally damaging energy sources.

Now, the construction industry can be classified in four sectors; such as, residential, commercial, industrial and heavy construction. Among all of them, residential and commercial are the sectors that contribute to the most amount of energy consumption due to their dominant user base. Residential and commercial buildings consumed the equivalent of 114 EJ worldwide in 2005 [31]. Residential electricity consumption is one of the fastest growing areas of energy use, especially in developing countries. World average per capita residential electricity consumption is about 600 kWh per year but reaches 1,500 kWh per year in Western Europe and is more than 4,000 kWh per year in North America (WEC, 2004) [31]. In the commercial sector, electricity consumption is also growing faster than the growth rate of the economy, especially in countries with air conditioning requirements. Making use of energy conserving practices in new and existing buildings could save as much as 34 percent of the projected primary energy consumption by the world's buildings by 2020 (Urge-Vorsatz et al.,2006) [31]. This estimate would represent a reduction of 52 to 57 EJ (3.8 to 4.7 billion tons of CO_2) by 2020 and a reduction of 79 to 84 EJ (5.8 to 6.9 billion tons of CO_2) by 2030 [31]. The potential global energy conservation in buildings by 2030 are equal to the current energy consumption for all uses in Europe. Little of the energy conservation potential in this sector has been captured, due to characteristics of markets, technologies, and end users that inhibit rational choices in building construction and appliance purchase and use [31].

Also, the WBCSD (World Business Council for Sustainable Development) identified buildings as one of the five main users of energy, where "megatrends" are needed to transform energy efficiency [32]. They account for 40% of primary energy in most countries covered by this project, and consumption is rising. The International Energy Agency (IEA) estimates that current trends in energy demand for buildings will stimulate about half of energy supply investments to 2030 [33]. The WBCSD identified buildings as one of the five main users of energy where "megatrends" are needed to transform energy efficiency [33]. The International Energy Agency (IEA) estimates that current trends in energy demand for buildings will stimulate about half of energy supply investments to 2030 [32].

In sectors such as residential and the commercial sector, the major part of the energy consumption that takes place in buildings, includes, energy used for controlling the climate in buildings, and for the buildings themselves, but also energy used for appliances, lighting and other installed equipment [33]. The energy conservation of new buildings determines the building sector's energy consumption for far longer than other end-use sectors components determine their sector's conservation. Buildings will typically be constructed to be used for many decades and, in some cases, for more than a hundred years. In other energy end uses, the capital lifetime for efficiency improvement will be, at most, a few decades [33]. Improvement of buildings' efficiency at planning stage is relatively simple while improvements after

Energy consumption in different sectors.

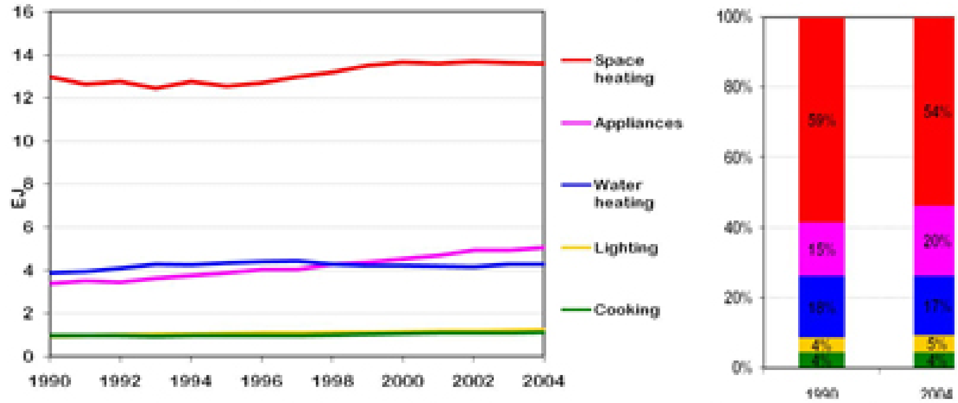


According to the IEA statistics for energy balance for 2004-2005,(2007 edition), the total final energy use globally accounts for 7209 Mtoe (Mega Tonnes Oil Equivalents).The residential and commercial sectors account for respectively 1951 Mtoe and 638 Mtoe, which is almost 40 % of the final energy use in the World[1]. The major part of this consumption is in buildings.

Fig.01 [33]

Their initial construction are much more difficult: decisions made during a building's project phase will hence determine conservation over much, if not all, of a building's lifetime [33]. Some measures to conserve energy are possible only during construction or by major refurbishment, likely to happen only after several decades [33]. Other improvements will be very cost effective or maybe even free or at negative costs when implemented at project stage, but can be expensive at a later stage [33]. Energy efficiency requirements in building codes or energy standards for new buildings are therefore among the most important measures for buildings' energy efficiency.

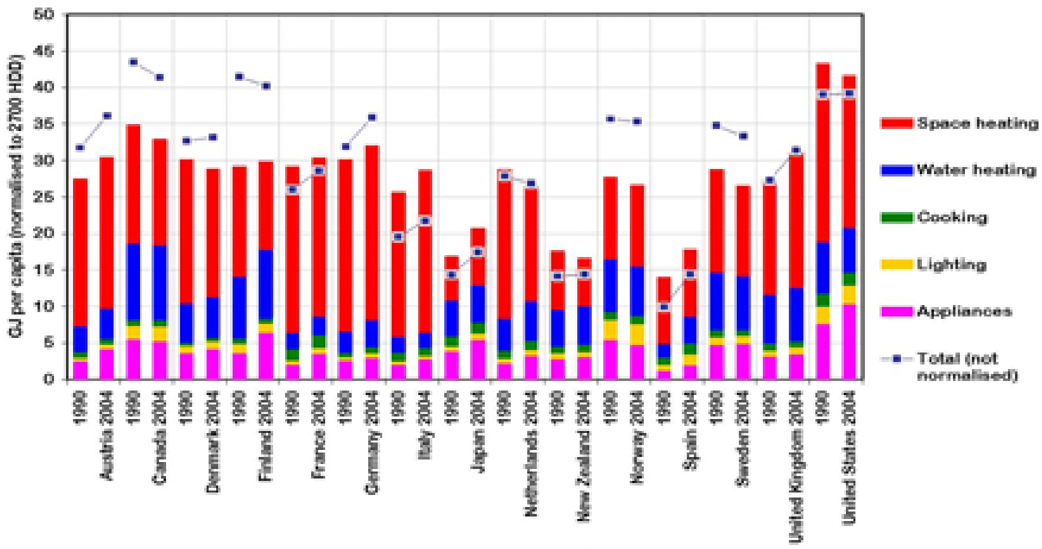
Energy use in residential buildings.



Source: 30 Years of Energy Use in IEA countries. A large part of the energy consumption in residential buildings are used for direct building related use such as space heating, which accounts for more than 50 % in selected IEA Countries.

These differences in the use of energy in different countries can best be illustrated by a subdivision of energy consumption in residential buildings, which is the most homogenous type of buildings.

Subdivision of energy consumption in residential buildings in select IEA countries.



Source: 30 Years of Energy Use in IEA countries[2]. As illustrated, the use of energy is different in individual countries both in concern of level as in the subdivision. The graph also shows issues on comparison and normalisation, which will be targeted later in this paper.

Fig.02 [33]

Building-related end-uses - heating, cooling, ventilation and the preparation of hot sanitary water - require approximately 75% of a residential building's energy demand [33]. For service buildings, the share of energy use for other purposes

will often be larger and for some types of service buildings it can be more than 50% [33]. Energy use for buildings in the US is substantially higher than in the other regions, and this is likely to continue (see Figure 03). Consumption in developing countries such as China and India will grow rapidly, however, and China's building energy consumption will be approaching Europe's by 2030, while India will have overtaken Japan. If current trends continue, commercial building energy use in China will more than
Figure 03 [32]

Double during this period. Energy consumption in Western Europe will rise only moderately and will remain flat in Japan. Building energy in Brazil will grow, but will remain relatively small in 2030 compared with other regions [32]. More than four-fifths of site energy use typically occurs in the operational phase of a building's life, as Figure 04 shows. The proportion of energy embodied in materials and construction will rise if operational energy efficiency increases and if building life spans shorten [32]. End uses vary by sector, region and climate. For example, refrigeration is a major user of energy in food retailing, while non-food retail uses substantially more energy for lighting than other sectors do. Food service and food sales are high-intensity sub-sectors, but the large amount of office space means this is likely to be the greatest overall energy user [32]. Energy use varies among residential buildings, but space and water heating are substantial components in most regions. This is true for the US despite the widespread use of energy for space cooling in hotter states [32].

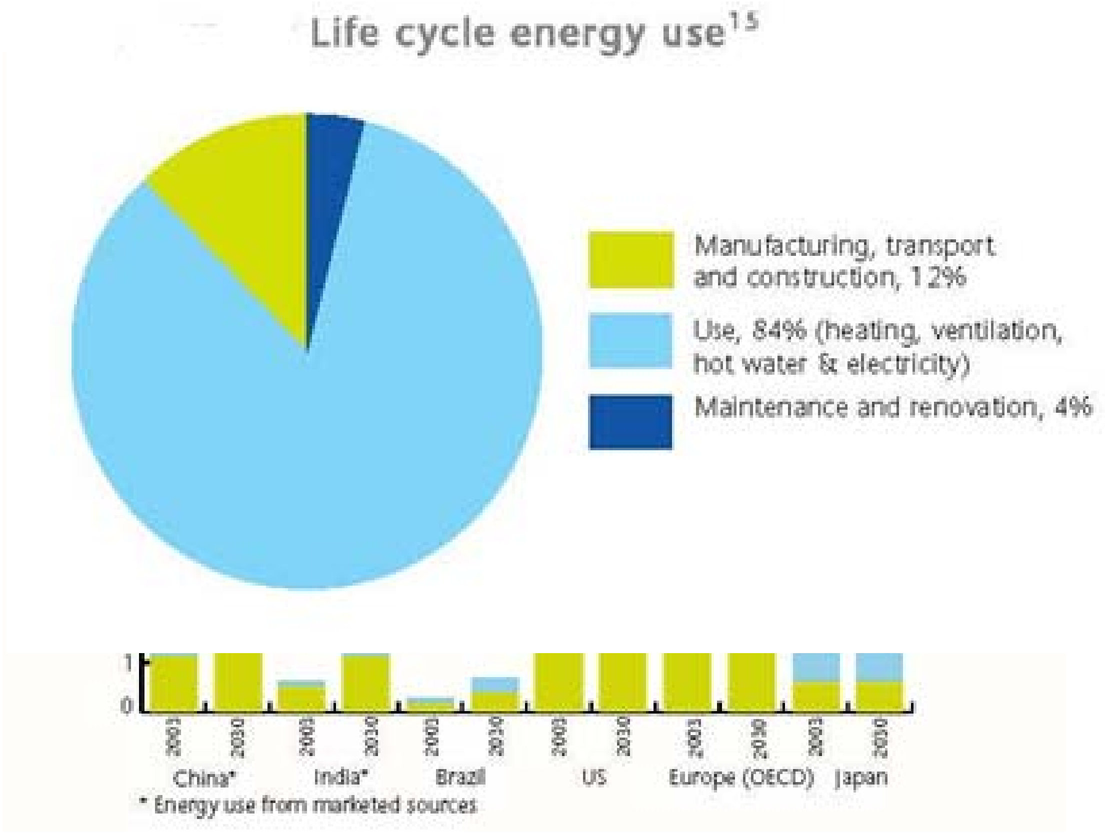


Fig.03 [32]

Therefore, in many developed and developing countries worldwide, the building codes and standards for energy conservation and consumption are set for high efficiency. In countries with large climatic differences the national building codes might includes values which are adjusted to the local conditions [33]. These are referred to as national building codes. In other countries, local states or regions establish energy efficiency requirements in buildings. This applies in particular to large countries with a federal government [33]. In this case, a model building code is often developed to cover the whole country, either on a public or as a private initiativee. Individual states or regions then modify the national model standard to local conditions; and must adopt this legislation, before it becomes mandatory [33]. Finally, some countries delegate the establishment of energy conservation clauses for buildings to local authorities [33]. In this case, the city council, regional government or federal state may autonomously set and enforce standards. This independent governance is now quite rare, particularly in OECD countries, where energy efficiency is seen to be far too important from a national perspective and *national development (my addition)* [33].

5A2. Development of Codes and Standards for Energy Conservation in Buildings and their Impacts

Most regulations for energy efficiency in buildings before the oil crises in 1973/74 are from northern regions with cold winters, where the climate can considerably influence public health [33]. Requirements on specific constructions with some thermal characteristics in these regions first appeared during the period between the two World Wars, when some countries regulated the introduction of simple insulation in the form of air layers in cavity walls or double layer floors of timber beam [33].

The first real insulation requirements for U-values10, R-values11 and specific insulation materials or multi-glazing, date back to the late 1950s and the early 1960s in Scandinavian countries [33]. These national requirements were intended to improve energy conservation and comfort in buildings [33]. Comfort was the prime motivation for raising the requirements – in a reflection of increasing standard of living, people wanted better and improved living conditions.
In many countries, the oil supply crisis of the early 1970s catalyzed the development of energy conservation requirements for buildings [33]. Those countries already enforcing conservation regulations generally raised their requirements during the early 1970s to further reduce energy consumption and decrease dependency on oil. During the 1980s and 1990s, energy conservation requirements were set or increased in most OECD countries. In part, this new legislation responded to the Kyoto Protocol, or other targets to reduce or stabilize CO2 emissions [33].

Today, mandatory minimum energy consumption requirements in the form of building codes or standards exist in nearly all OECD countries [33]. However, substantial differences persist between legislation of the states, regions and cities. Regulations for energy conservation in buildings in developing countries, and especially in rapidly developing countries such as India and China, seeks to improve comfort and to reduce the dramatic increase in energy consumption in this sector with the economic capacity to install cooling or heating systems [33].

Now, as the countries around the world start to integrate these energy conserving building standards into their national and regional programs, the reduction in energy consumption in buildings has been evident. For example, In 1961 Denmark established one of the first building codes which systematically regulated energy consumption [33]. Since then, building codes have been updated several times, including major changes in 1972, 1979, 1997, and in 2006 [33]. As illustrated in Figure 5, studies of existing buildings track the trend of declining energy consumption in the context of rising efficiency requirements. A similar trend is shown in other countries: buildings' improved energy performance follows the introduction and strengthening of building codes with lapse between promulgation and improvement corresponding to the strength of local law enforcement [33].

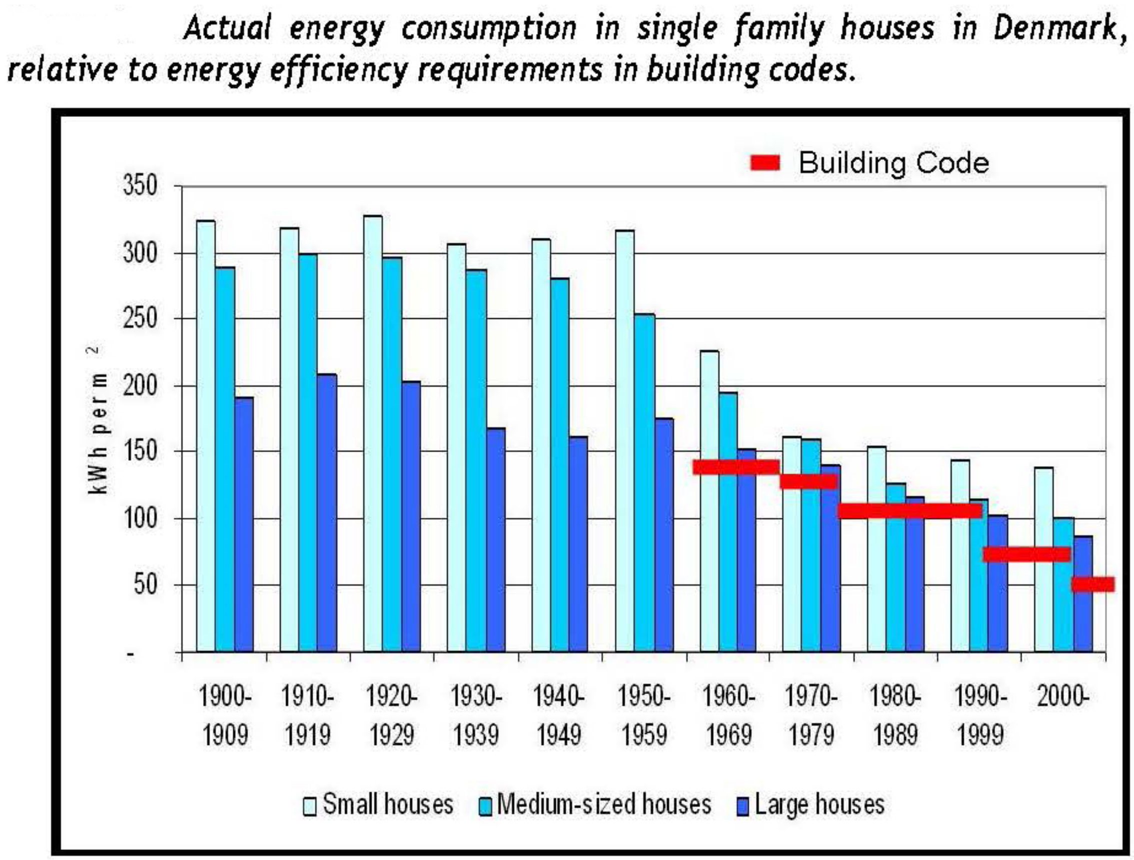


Fig.04 [33]

5A3. Energy conserving building standards around the world

Though most energy efficiency requirements in building codes followed local, state or national tradition, the past decade has shown a trend in supranational collaboration to develop international energy conserving requirements or standards [33]. Examples are the US based Energy Efficiency standards (IECC 200415 and ASHRAE 200416) which are used in US and Canada, and the European Energy Performance in Buildings Directive (EPBD) that required member states of the European Union to establish requirements for energy efficiency in new buildings, effective January 2006. To supplement the EPBD, the European Union aims to establish a model building code for energy efficiency for the European region (2006 EU Action Plan for End-use Efficiency) and to develop CEN standards for energy performance calculation. These CEN standards are on the way to be amended and adopted as ISO standards too. Most countries have started with one common standard for energy efficiency, but have over time developed separate standards for small and simple residential buildings and for large, complex or non-residential buildings, in consideration of the dissimilar energy performance [33].

5A4. Leadership in Energy and Environmental Design (LEED)

LEED (Leadership in Energy and Environmental Design) is a voluntary, consensus-based, market-driven program that provides third-party verification of green buildings [34]. From individual buildings and homes, to entire neighborhoods and communities, LEED is transforming the way built environments are designed, constructed, and operated. Comprehensive and flexible, LEED addresses the entire lifecycle of a building. Participation in the voluntary LEED process demonstrates leadership, innovation, environmental stewardship and social responsibility. LEED provides building owners and operators the tools they need to immediately impact their building's performance and bottom line, while providing healthy indoor spaces for a building's occupants [34]. LEED projects have been successfully established in 135 countries [34]. International projects, those outside the United States, make up more than 50% of the total LEED registered square footage [34].

LEED certified buildings are expected to be energy efficient and resource sensitive compared to conventional buildings. By following the LEED certification and its guidelines, the building adhere to environmental building practices and in turn produces healthier work environment and microclimate for the occupants. Since, it's relatively new regulation in building sector, there is dearth of professional conversant with the LEED certification and its requirements. This leads to time delay and even in some cases the suspension of the project when a particular level of raring is being targeted in terms of performance of the building.

However, adherence to LEED certification usually greatly impact the energy performance of the building and incurs financial savings by reduced energy consumption. Also, a healthy indoor environment affect the health of the occupants positively and improves the work efficiency significantly. These advantages usually counter the initial additional cost associated with adopting the LEED rating system for a newly constructed building.

Although the certification is being adopted in USA and other countries with some modifications, the requirement of customizing the LEED guidelines with reference to region specific climatic and geographical conditions remains. At presently cost associated with preparing the application for LEED certification is greater than the financial benefits it promises to bring to the building developers and owners. Therefore, the resistance and opposition to LEED prevails in USA and other countries as well. In sum, LEED can be a substantial design guide as well as performance evaluator metric if it had been customized according to the regional climatic parameters, and cost associated with the process of LEED certification is somewhat decreased.

5A5. Critical analysis of Energy Conservation in Buildings in INDIA

India is emerging both as an economic powerhouse and as India's economy charges ahead, the country needs to produce more energy to provide a better life for its people, many of whom live in rural areas and are very poor. At the same time, India has recognized that tackling climate change is in its own national interests. The nation is taking concrete measures to constrain its own emissions and to protect its people from climatic disruptions [39].

India is at a crossroads in its development path. India's building-occupied area is projected to skyrocket from 8 billion square meters in 2005 to 41 billion in 2030. To keep pace, India's energy production must grow 6.5 percent per year from 2011 to 2017 [36]. Buildings already account for more than 30 percent of the country's electricity consumption, and nearly 70 percent of the buildings in India that will exist by 2030 have yet to be built. Under a business-as-usual scenario, India's current power production is and will be unable to meet the expected demand [36]. Energy efficiency will be the cheapest, fastest way to close the energy demand and supply gap. Incorporating energy-efficient windows, lighting, and air-conditioning systems at the design stage for new construction is more economical than costly retrofits [36]. If developers across India implement standard energy efficiency measures in new construction and major retrofits, the country could avoid the need for 2,988 megawatts (MW) of generation capacity and save $42 billion annually [36].
State and local governments, real estate developers, and financial institutions are critical to the successful development and implementation of energy-efficient buildings [36]. While existing government policies, building-rating systems, and active stakeholders do provide a foundation for accelerating progress in energy efficiency, as India's real estate market continues to grow, the current policy framework needs to be further developed and implemented by coordinated stakeholder action [36]. It is therefore critical that these three leading stakeholder groups -- state and local governments, real estate developers, and financial institutions -- drive development and adoption of energy efficiency measures in the buildings market for new construction and major retrofits. Accelerating energy efficiency while India experiences an unprecedented growth in its buildings market provides a singular opportunity to generate tremendous financial benefits,

while improving public health, combating climate change, and closing the widening gap between India's energy production and demand [36].

Considering the energy conservation as the cheapest and fastest way to meet the gap between supply and demand. Implementing energy conserving measures at the initial phase of construction becomes the important for national policy. Buildings account for more than one-third of the electricity consumption in India Figure 06 [36]. The overall share of the commercial sector in India’s electricity consumption is 6.5 percent, growing at a rate of 11 percent to 12 percent over the last few years [36]. Commercial buildings new office spaces, information technology (IT)-based offices and data centers, multispecialty hospitals, luxury hotels, and retail malls—are becoming more energy-intensive [36]. The rate of increase in commercial electricity consumption is much more rapid than the annual 9 percent rate of increase in the floor area of commercial buildings [36].

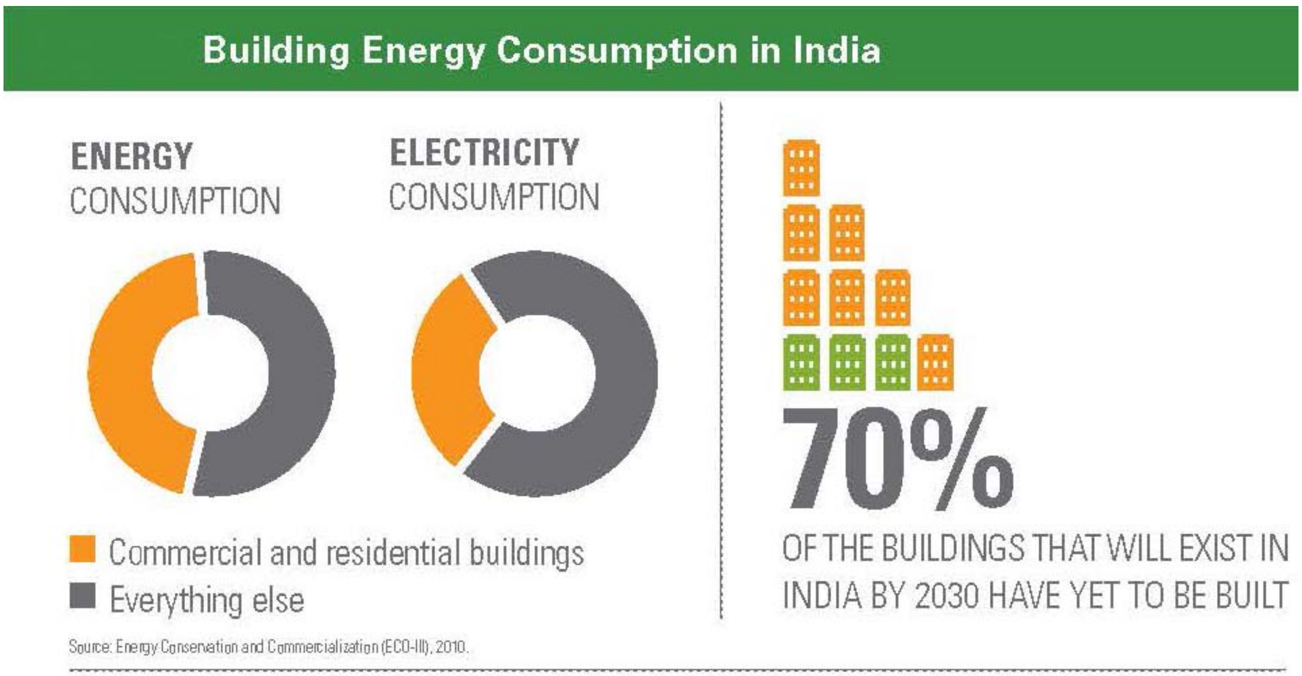


Fig.05 [7]

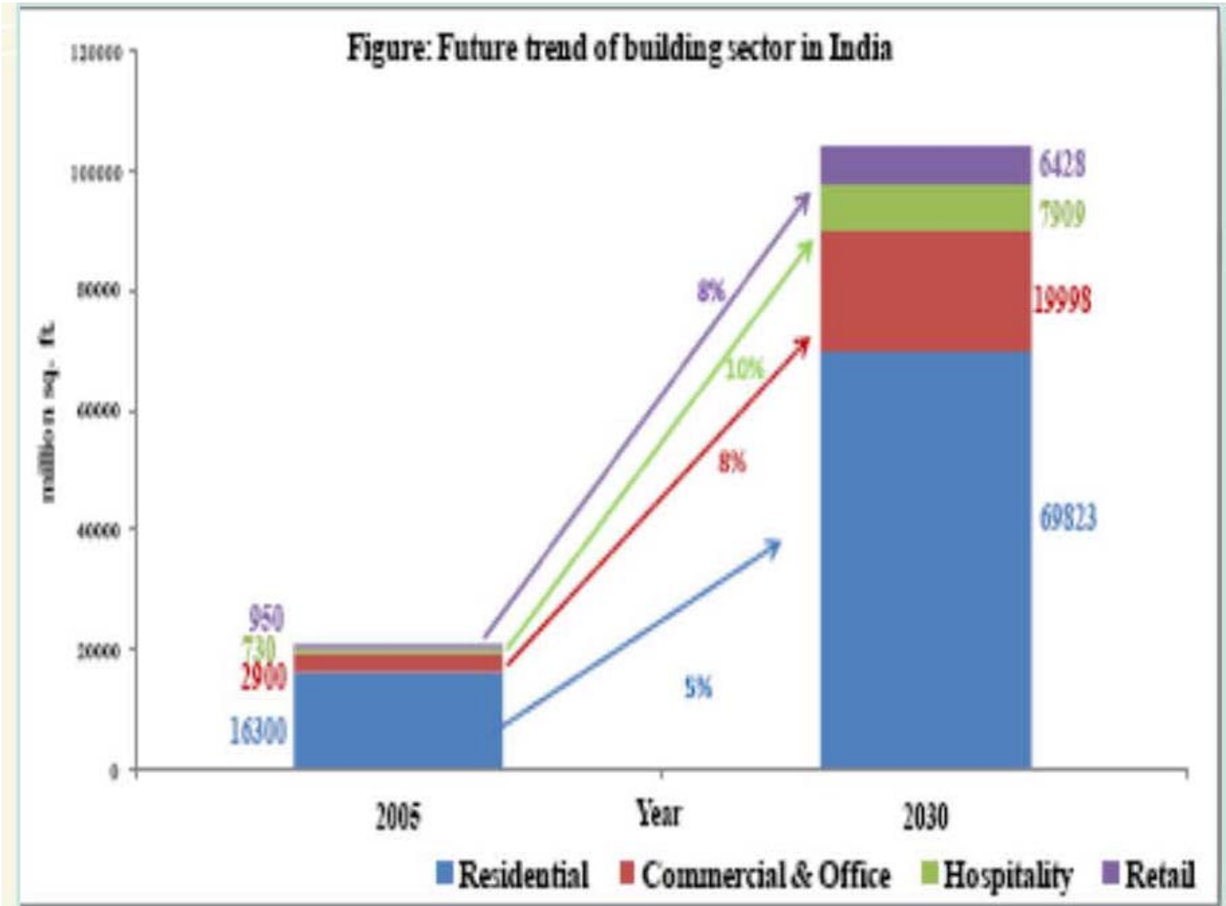


Fig.06 [40]

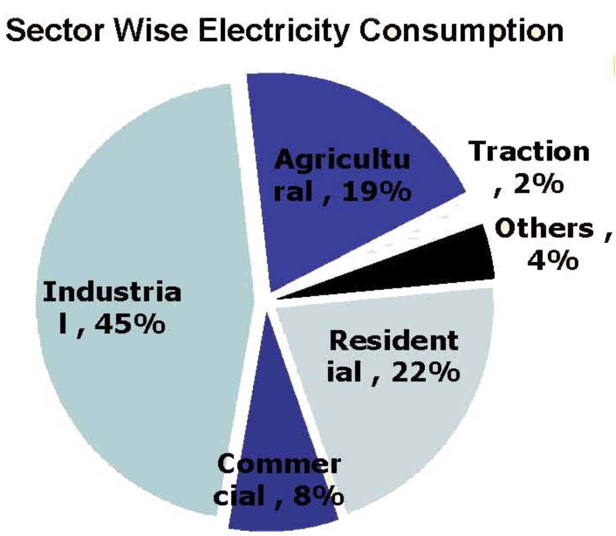


Fig.07 [40]

In order to address the rising energy demand (Figure 08), national and private organizations have been working to develop and implement energy conserving measures, rating systems and policies across the country. The role of such organizations is to maintain and keep the policies in check with the growth of the real estate sector in the country.

<u>Energy Conservation Building Code the Energy Conservation Building Code (ECBC)</u>
Developed by the Bureau of Energy Efficiency (BEE), prescribes a minimum standard for energy use in new buildings and major retrofits.50 The load requirement for buildings to comply is 100 kW or 120 kilovolt-amps (kVA), which enables commercial and high-rise residential buildings (approximately five stories or higher) to come under the code's purview [36]. The ECBC establishes minimum requirements for energy-efficient building design and construction. The code is voluntary at the national level, and the Ministry of Urban Development and state governments are responsible for its implementation and enforcement [36].

<u>Environmental Impact Assessment for Buildings</u>
The real estate developers are required to obtain an Environmental Impact Assessment (EIA) clearance from the Ministry of Environment and Forests before constructing projects greater than 20,000 square meters [36]. The EIA is a comprehensive assessment of resource use, including energy, water, air, land, and ecological impacts [36].

<u>National Building Code</u>
The National Building Code (NBC) of India is a comprehensive building code which provides guidelines for regulating construction activities [36]. It serves as a model code for adoption by all agencies involved in building construction. The NBC contains administrative regulations and general building requirements, as well as stipulations regarding materials, structural design and construction, and building and plumbing services [36].

<u>Leadership in Energy and Environmental Design (LEED) India</u>
LEED India is the localized version of the international rating system and is administered by the Indian Green Building Council (IGBC). Currently, there are 1,482 LEED India registered buildings and 214 LEED certified buildings, representing 1,012.92 million square feet of registered green building footprint. According to IGBC, projects that comply with the ECBC also qualify for LEED India ratings, provided they are equivalent to specific standards, such as ASHRAE 90.1-2007 [36].

<u>Green Rating for Integrated Habitat Assessment (GRIHA)</u>
GRIHA is the national rating system for green building design, developed and implemented by The Energy and Resources Institute (TERI) and the Ministry of New and Renewable Energy (MNRE) [36]. If buildings contain fully air-conditioned interiors, ECBC compliance is mandatory for GRIHA ratings [36]. If buildings are naturally ventilated, only partial ECBC adoption is required. All new central government and public sector buildings are to comply with the requirements of at least three-star GRIHA ratings [36].

<u>BEE Buildings Star Rating System</u>
BEE has a star rating program based on the actual performance of a building in terms of its specific energy usage in kWh/sq m/year [36]. The program rates buildings (office buildings, shopping malls, hotels, hospitals, and IT parks) on a one- to five-star scale, with five stars being the most efficient. The rating considers operational characteristics that define building use, hours of operation, climatic zone, and conditioned space [36]. It allows comparison to a peer group representing buildings with similar primary function and operating characteristics [36].

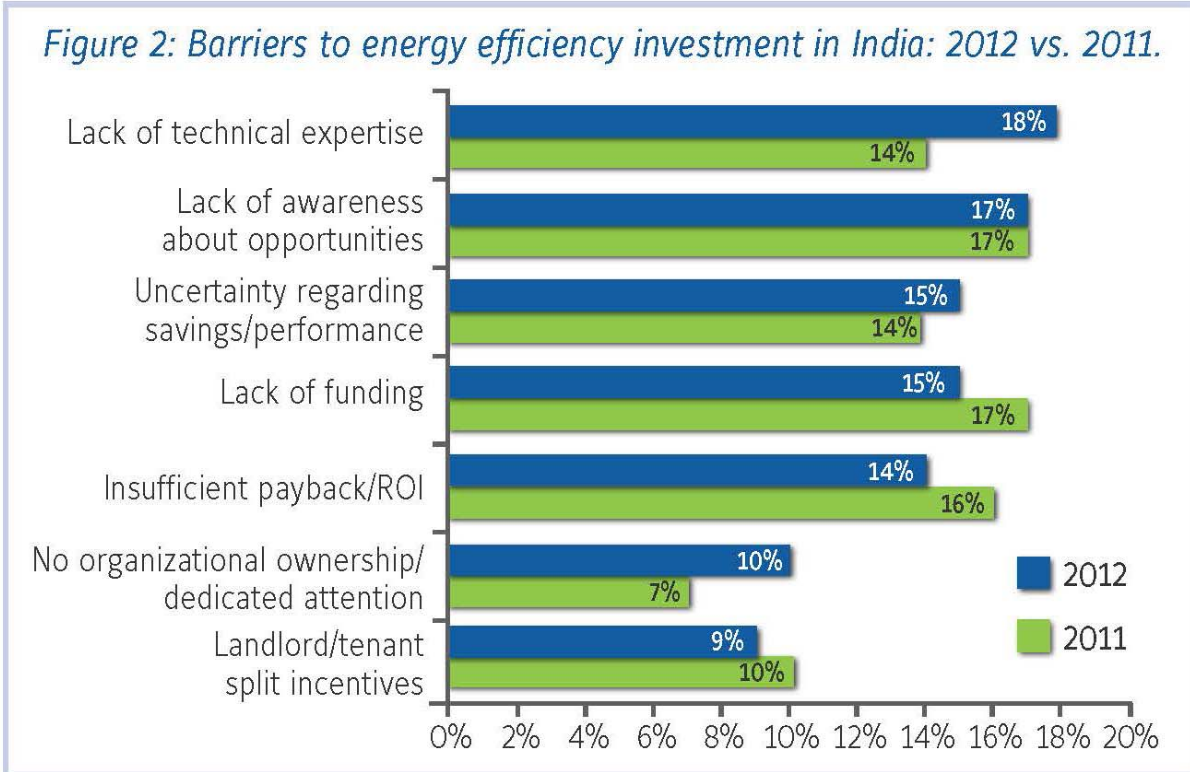


Fig.08 [41]

At present, there are various barriers in the development and adoption of energy conserving measures (Figure 09) and these barriers are one of the many reasons for the reluctance in user group and developers to adopt these energy conserving measures. This creates lack of demand of energy saving designs and ultimately leads the designers to ignore such considerations. Apart from that, the quantitative difference in energy performance in by adopting such measures is not clear at present. However, this perception can be addressed and changed by introducing, information bulletins, incentives, standards, grading systems, labelling, financing, and marketing. Government, developers and financial institutions can help the India make this paradigm shift. And, India's unprecedented growth in real estate sector can earn substantial financial savings if energy conservation delineates India's growth trajectory.

5A6. Discussion of results

Considering the findings and results of this section of the paper, it can be inferred that; all around the world, a substantial amount of work is being done in order to instill the energy conservation in building industry. However, the barriers to full adoption and integration are significant as well. Which precisely deters the further adoption of such energy saving measures.

In case of India, where there is rapid growth in real estate sector, the framework for the energy conservation is building sector is still under development and relatively new to the industry. Barriers to adoption of such measures are even greater in India. However, actions of government and private organizations have been working to address this scenario and to integrate energy conserving clause into everyday construction practices throughout the country.

5A7. Conclusion

At present, the implementation of energy conserving standards and regulations is cost intensive if compared with total investment, interest rates, mortgage cost, and accumulated energy cost of a building. Even then, the opportunities of improvement are substantial if addressed through an environmentally sensitive construction ideology. In the US show that energy consumption can be reduced by 75 % without additional total costs for the owners [33]. IEA studies on scenarios in show the possibility of a 70 % reduction in most OECD countries over longer time [33]. However, in some countries such as Sweden, Denmark and the Netherlands the demands for new buildings are closer to the least cost optimum and the possible reduction is smaller [33].

Since the energy conserving standards and regulations in developing countries are either in development stage or are not place, the possibility of integrating the energy conserving standards into national development strategy can be relatively simple and effective. If advanced energy conserving concept of passive houses became more commonly adopted on the market these technologies would become less expensive and this could increase the cost effectiveness of these houses and increase the saving potentials even further [33]. A targeted policy to increase the development of more efficient solutions through demonstration projects, research and development could accelerate this development. Such a policy can catalyst the design and development of energy conserving design models such as Passive House and Zero Carbon House eventually.

Apart from new design of buildings, it is the refurbishment and renovation of existing buildings that account for a substantial energy conservation in building sector. The process of renovation can contribute significantly if standardized for energy conserving material usage and high performance of design solutions. It is estimated that the total feasible potential for energy savings by renovation and refurbishment in most OECD countries will be around 50 % of the actual consumption [33]. In transition economies this potential will be even larger, because of lower energy standard of the existing buildings [33]. In fast developing countries outside OECD the feasible potentials is estimated to be larger too, but the savings in these countries will be reduced by an increase in the comfort levels both for cooling and heating [33]. Not all buildings will be renovated before 2030 since a full renovation cycles will take around 30 – 40 years, and a policy to demand improvement of efficiency by refurbishment would not be fully effective. The possible saving potential for these measures should therefore be estimated to be around 15 – 25 % of the consumption in the existing buildings [33].

All in all, the potential for energy efficiency in buildings is very large both in new and in existing buildings. Over time the energy efficiency in buildings can be reduced by more than 50 % alone with measures, which are feasible already today [33]. And because buildings are renovated after 30 – 40 years, some existing buildings will not yet have been refurbished in 2030 and the potential to cost-effectively raise buildings' efficiency before 2030 is smaller than the total potential. The potential for energy conservation in 2030 is therefore estimated to 30-50 EJ (30000 – 50000 PJ) [33].

The requirement for energy conservation in buildings will rise with the passing years as will the demand for the energy use. However, the technological development will follow and will help future professionals to address the energy saving challenges without compromising on the comfort value of the design solution. International and national standards, policies, regulations, certifications, and renovations are all the tools to address the need for energy conservation in the energy intensive building industry. However, these tools may only be helpful when there will be a significant change in the approach towards energy consumption and conservation by the society the world as a whole.

5B. Assessing the Potential of Conservation in Buildings

To be able to assess the potential for energy conservation while maintaining reasonable comfort, we first need to understand the terms. There are three main concepts to understanding energy conservation potential and several approaches used to define it. The first concept is the definitions themselves, whether technical, economic or some other alternative. "Technical potential refers to the amount of energy savings that would occur with complete and instantaneous penetration of all measures in applications where they were deemed technically feasible from an engineering perspective. Economic potential includes the technical potential of only those measures that are cost effective when compared to the supply side alternative or the price of energy." [1] The second concept is the assessment of that potential or total resource cost, an example of which would be embodied energy. The third concept is the comparison between technologies and their relative costs and benefits. [1]

Human comfort can be defined as conditions under which the least amount of energy is needed to adjust to the environment and wherein the most energy is freed for productivity. [2] Many factors affect human comfort, air temperature is the most significant ambient factor that affects internal temperature and level of comfort, but is it not the only factor involved. The major elements of climatic environment that affect human comfort can be categorized as air temperature, radiation, air movement, and humidity. Means by which the body exchanges heat with its surroundings can be classified into four main processes radiation, conduction, convection, and evaporation. [2]

Comfort does not however only refer to the physicality of the term. The idea of comfort can be linked to the other concepts of conservation potential as well, such as economics. Economic stresses can cause discomfort. Therefore, to be able to assess the potential for energy conservation while maintaining reasonable comfort, the means in which energy conservation is attained must address both the physical comfort aspect as well as the economic comfort aspect.

Adapting architectural design to utilize the climatic elements needed to restore or maintain comfort conditions should be the starting point for any architectural design aiming at energy conservation. This approach, commonly referred to as passive design considers the thermal processes of convection, conduction, absorption, and radiation into a design, as a way to maintain comfort levels and reduce or eliminate the need for mechanical systems for these purposes. It is the leading approach to energy conservation in buildings as well as the most economical.

Integrated building design or IBD is another effective approach to energy conservation in buildings. IBD involves all participants such as the owners, engineers, architects, and consultants early on in the design phase. They work together cooperatively across the different disciplines. This can greatly improve building performance with lower costs, less effort and fewer disruptive changes. IBD can be applied to the building as well. Building performance depends on the performance of the individual elements as well as how they perform as integrated systems. The building envelope is of particular importance. It is the starting point of energy conservation in buildings and the main determinant of the amount of energy needed to heat, cool, and ventilate. The envelope typically requires an intricate integration of both passive and active strategies. More specifically, it determines how airtight a building is, how much heat is transmitted through thermal bridges and how much natural light and ventilation can be used.

Another aspect of building design with energy conservation potential is the employment of energy conserving materials**.** In most cases, additional material or more efficient materials, required for energy conservation, will cost more upfront but will lead to lowered costs of heating and cooling, so the money spent should be quickly recovered.

There are three types of energy conserving materials. There are materials with less embodied energy, materials that conserve energy, and there are materials that consume less energy or are more efficient. "Embodied energy is the total energy sequestered from a stock within the earth in order to produce a specific good or service including extraction, manufacture, and transportation to market." [4] Recycled materials are good examples of materials with less embodied energy. Recycling scrap steel reduces the energy produced in making the steel by 75%. Some examples of materials that conserve energy are thermal mass materials such as concrete or stone. These materials lose less heat in winter and gain less heat in summer. Combined with passive design strategies and a well-constructed envelope, utilizing these materials in a design can conserve massive amounts of energy. The way in which these materials hold and release heat, by radiation, works well with maintaining indoor comfort levels as well, since we use radiation as a means of heating and cooling ourselves. The third type of energy conserving material is those that consume less energy or are more efficient. Examples of these would be LED lights whose efficacy [lumen/watt] measures tenfold that of conventional incandescent. Low-E or low emissivity windows have substantial energy conserving benefits as well. They typically cost between $60 - $110 each, only 10-15% more than clear glass windows but can reduce heat flow through the glass by half, which will help reduce heating and cooling costs by about 20%. [5]

The idea of increased efficiency applies to more than just materials, but to building systems as well. Heating, ventilation, and air conditioning or HVAC systems consume about 37% of the total energy in a building. Increasing the efficiency of these systems can greatly reduce energy consumption. [6] The use of high performance HVAC equipment can result in considerable energy, emissions, and cost savings. Typically, a 30% reduction in annual energy costs can be achieved with a simple payback period of about three to five years. Extended comfort includes employing concepts such as providing warmer, but drier air using desiccant dehumidification in summer, or cooler air with warmer windows and warmer walls in winter. In addition, high performance HVAC can provide increased user thermal comfort and contribute to improved indoor environmental quality. [7]

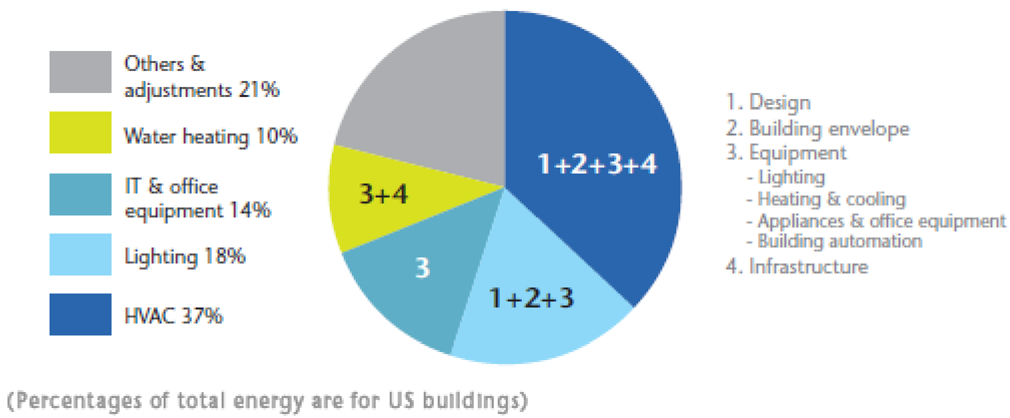


Fig.09 [41]

The impact on energy conservation through the implementation of new construction such as zero energy or near zero energy buildings is substantial for the long term, but the potential to reduce energy consumption in existing buildings may be more important. Retrofitting existing buildings has the most potential for energy conservation because most of the changes are simple and cost effective and because progress can begin immediately. The technology and knowledge to cut building energy use exist today and the upgrade can actually enhance levels of comfort.

According to a study done by the Pacific Northwest National Laboratory, lighting is the end use that continues to have the largest and most cost effective energy saving potential in existing buildings. Refrigeration systems and components are the second largest source with HVAC and office equipment following. The retrofit with the least potential is changing the building design or materials, there is great potential for energy savings, but it is the least cost effective. Overall, the study indicated that a reasonable range of economic and energy saving potential between 10% and 20% could be achieved. Since buildings are responsible for at least 40% of energy use in most countries, these savings can be significant. [1]

The behavior of occupants in a building can have as much impact on energy consumption as the efficiency of the equipment. Behavior is influenced by economic, social, and psychological factors that influence both the buying of equipment and the use of energy. Using energy can be considered a symbol of progress and affluence and in the developed world it is greatly taken for granted, leading to unnecessary waste. One of the largest barriers in the way of energy efficient behavior is the rebound effect. The rebound effect is the reduction of energy savings leading to additional activity through greater use of the same product of for another energy using action. [2] Some examples of the rebound effect include driving a more efficient car further, leaving lights on because they are energy saving bulbs, or turning the heat up or AC down with a more efficient HVAC system.

The transition to using energy more efficiently is difficult because it requires widespread changes in habits, however energy conserving actions can be influenced. Cost is important, especially energy cost as a share of total expenses but the information must be available to stimulate action. Cultural, educational, and social factors, including the concern for the environment, also influence people's attitudes. Information and education are the key elements to change knowledge into action.

Government implemented standards are another way to stimulate behavioral changes and energy conserving actions. In the United States the Department of Energy and the National Energy Conservation Policy Act (NECPA) serves as the underlying authority for Federal energy management standards, goals and requirements. The NECPA sets standards for how much energy a building is permitted to use and the standards are revised annually. The Department of Energy is also in charge of the energy building codes. Europe has a similar government entity that regulates energy use in buildings however their standards are much higher and use only about a third as much energy as the United States. In fact, the EU is aiming for a 20% reduction in energy use by 2020 and an 80% reduction in energy use by 2050. These types of standards also help to change the behavior of people and how they use and or waste energy. [9]

5C. Embodied Energy

The embodied energy in building materials has been studied for the past several decades by researchers interested in the relationship between building materials, construction processes, and their environmental impacts. Buildings are known to be significant consumers of energy, water, and raw materials. They are estimated to consume upwards of 50% of available raw materials. [10] Energy efficiencies and conservation can be increased by simply setting and adhering to better standards of material and product use. As new building construction nears almost $900 billion for 2012, it's becoming more important and even more critical to evaluate the costs of buildings and the subsequent energy they use. [11]

Energy is not only needed to run a building, it also takes energy to create the building products and build it. Embodied Energy is the total sum of all the energy required to produce goods or services while considering that amalgamated energy as being embodied in the product itself. The concept of embodied energy is useful in determining the effectiveness of energy-producing or energy-saving materials or devices within buildings, i.e. - does the material or device produce or save more energy that it took to make it? Also, due to the fact that energy-inputs usually entail greenhouse gas emissions, studies of embodied energy allow researchers to make decisions whether a product contributes to or mitigates global warming.

Embodied energy becomes an accounting method which aims to find the sum total of the energy necessary for an entire product life-cycle. Determining the parameters for what constitutes this life-cycle includes assessing the relevance and extent of energy inherent in materials or products through reviewing raw material extraction, transport, manufacture, assembly, installation, dis-assembly, deconstruction and/or decomposition, as well as human and secondary resources. The more processes a product goes through, the higher its embodied energy value will be. It's important to note these values are quantifiable and all processes can be accounted for, including processes such as raw material extraction in distant upstream and demolition and disposal in the farthest downstream. [12]

To very simply define the arrangement aspect of embodied energy, it is the full amount of energy (from various sources) needed to transform a product from raw materials in the ground to the final result. This includes finding the raw materials, processing and manufacturing them as necessary, transporting them to site, and putting and combining them together. Thus, embodied energy of a building is the total energy required to construct it and therefore the energy that has become inherent within the materials. This energy value of a building is so large; it cannot be recovered during the lifetime of the building, regardless of the building's operating, unless it is mostly recycled at the end of its life. [13] During the demolition process, the existing materials of the building are recycled and the life cycle of the embodied energy continues on through the re-purposed materials, which can be partially amortized into its new location. Savings from recycling of materials for re-use or reprocessing varies considerably, for example, with savings up to 95% for aluminum but only 20% for glass. [14]

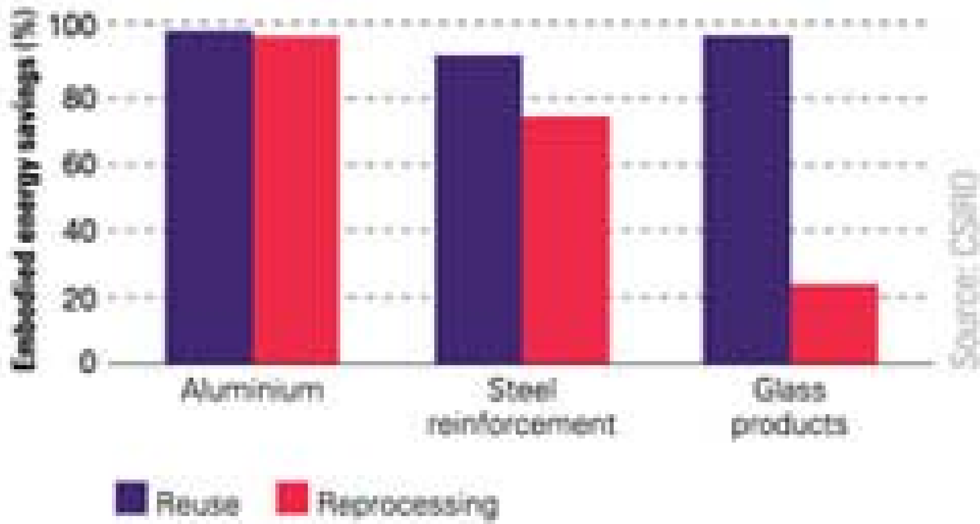


Fig. 10 [13] some reprocessing may use more energy, particularly if long transport distances are involved.

There are two forms of embodied energy typically considered in buildings: initial embodied energy and recurring embodied energy. The initial embodied energy in buildings represents the energy consumed in various onsite and offsite operations like construction, prefabrication, transportation, and administration. This includes energy inputs in construction and assembly on site, prefabrication of building components offsite, and transportation involved in various onsite and offsite processes. Within the initial embodied energy there are two components, direct and indirect energy. Direct energy refers to the energy used to transport building products to the site, and then to construct the building; and Indirect energy is the energy used to acquire, process, and manufacture the building materials, which includes any transportation related to these activities. The recurring embodied energy in buildings represents the energy consumed in manufacturing the building materials, in renovation, refurbishment, and demolition processes of the buildings. This includes initial embodied energy, recurrent embodied energy and demolition energy. Initial embodied energy is consumed during production of materials and components and includes raw material procurement, building material manufacturing and finished product delivery to the construction site. Recurrent embodied energy is used in various maintenance and refurbishment processes during the useful life of a building. Demolition energy is expended in processes of building‘s deconstruction and disposal of building materials. [15]

Embodied energy is typically measured as a quantity of non-renewable energy per unit of building material, component, or system. For example, the value of embodied energy may be expressed in Joules (J, MJ, or GJ) per unit of weight (kg or lb) or area (square foot or meter). The process of calculating embodied energy is complex and involves numerous sources of data. Often, differing parameters will cause variation and inconsistency in embodied energy results, identifying the need to develop a protocol to standardize the embodied energy calculation process.

The measures of embodied energy are implicit in the associated environmental implications of resource depletion, greenhouse gases, environmental degradation, and reduction of biodiversity. As a typical rule of thumb, embodied energy is a reasonable indicator of the overall environmental impact of building materials, assemblies, or systems. However, embodied energy must be carefully weighed against performance and durability since these may have a mitigating or compensatory effect on the initial environmental impacts associated with embodied energy. [15]

Up until recently the values of operating energy were considered more substantial in the total life cycle of energy in a building. However, due to advent of energy efficient equipment and high performance materials, the potential for curbing operating energy has increased and allowed a shift of focus to the energy inherent in the materials themselves.

Thus, the current emphasis of energy conservation has shifted towards measuring embodied energy in building materials.

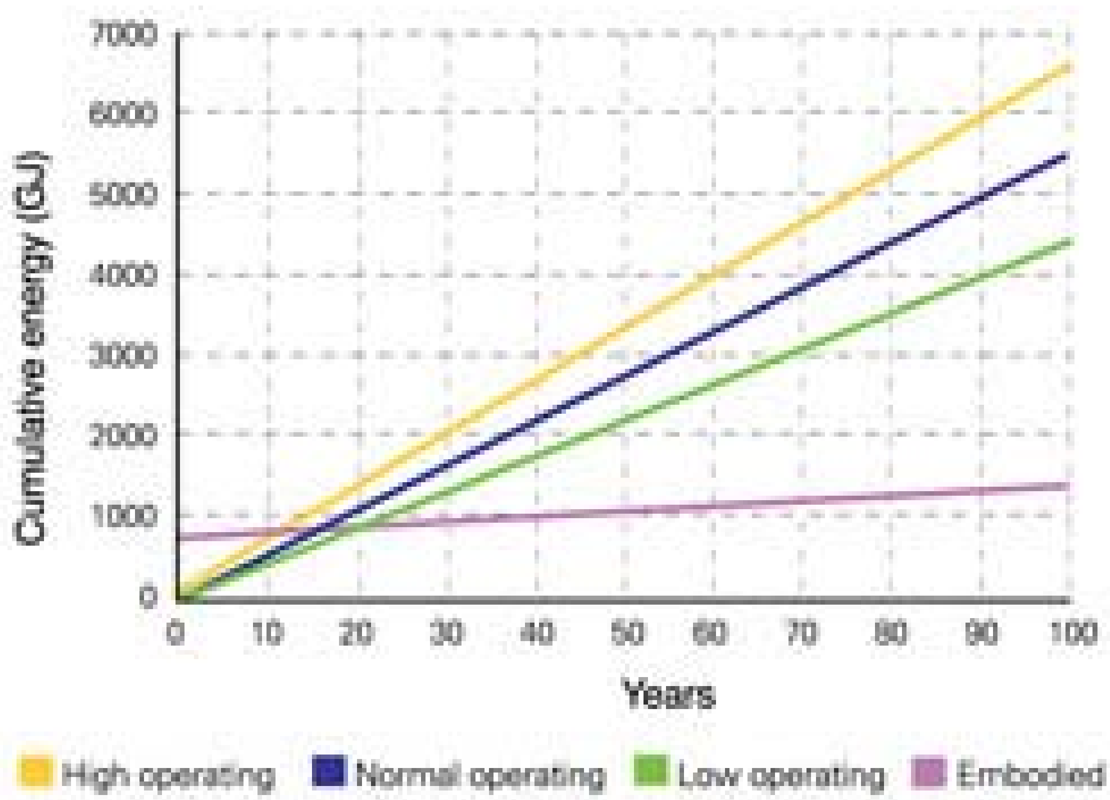


Fig.11 [14]

The measure of embodied energy in buildings varies considerably. Embodied energy can depend on the purpose of the building, the materials used for construction, and the source of these materials. It is for this reason data for a building material in one country may differ significantly from the same material manufactured in another country. In looking at it closer, embodied energy is also related to the durability of the building materials, components and systems installed in the building, how well these are maintained, and the life of the building. One can expect, the longer the life of the building, the greater the expected recurring energy consumption. [16]

This relationship is a direct result of what is referred to as differential durability, which is a term used to describe how the useful service life of building components, such as structure, envelope, finishes and services, differs - both between components, and within the materials, assemblies and systems comprising the components. It also can be used as the description of the whole building system by comparing between the service life of the building and its functional obsolescence. It is typical, with exception to structural elements, that all of the building components require varying levels of maintenance, repair, and replacement during the life cycle of the building. The extent and intensity of these recurring embodied energy demands vary significantly, depending on how appropriately the durability of materials, assemblies and systems are harmonized, and their accessibility for periodic maintenance, repair, and replacement. [17]

As buildings become more energy-efficient, the ratio of embodied energy to lifetime consumption increases. Clearly, for buildings claiming to be "zero-energy" or "autonomous", the energy used in construction and final disposal takes on a new significance. [15] However, it also applies to older buildings as well, particularly when it comes to demolition. Mike Jackson demonstrates that new buildings' life span must reach 26 years to save more energy than the continued use of an existing building. As building energy efficiency increases, embodied energy consumes an even larger proportion of life cycle energy consumption. Jackson finds that if a building were demolished and partially salvaged and replaced with a new energy efficient building, it would take 65 years to recover the energy lost in demolishing a building and reconstructing a new structure in its place. That is longer than many modern buildings survive. According to Jackson, preserving and upgrading a building is far more energy and carbon efficient than knocking it down and building new. Calling the new building "green" when it replaces an existing building is a farce when it takes so much energy to build. It's important to understand what matters, which is the embodied energy of the building's future, not the past. [18]

The focus must continue to go beyond energy conservation through negating operating energy use; as there is a risk that as buildings becomes more energy efficient over time, the relative proportion of embodied energy in the total life cycle energy could increase. Operational energy conservation may be accomplished with readily available energy efficient appliances, advanced insulating materials, and the optimized equipment for building performance. i.e., an increase in the number of Energy Star labeled home appliances in the United States could reduce operational energy gradually. While representing a timely and necessary advance, simply relying on increased energy efficiency standards can place an inequitable burden on the construction sector. Embodied energy, however, can only be reduced if low energy intensive materials and products are selected at the initial stages of building design; materials and products that not only have lower embodied energy values, but also have less need for future maintenance or replacement. [16] Other methods to reduce the embodied energy of buildings are: designing for long life and adaptability, using durable low maintenance materials, ensuring materials can be easily separated, avoiding building bigger houses than needed

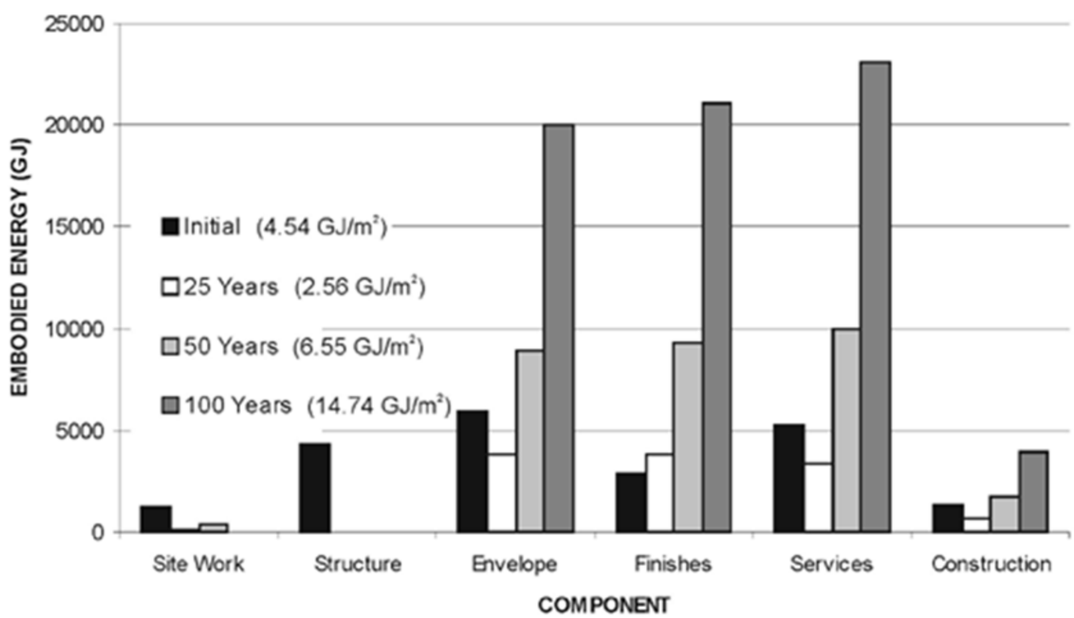
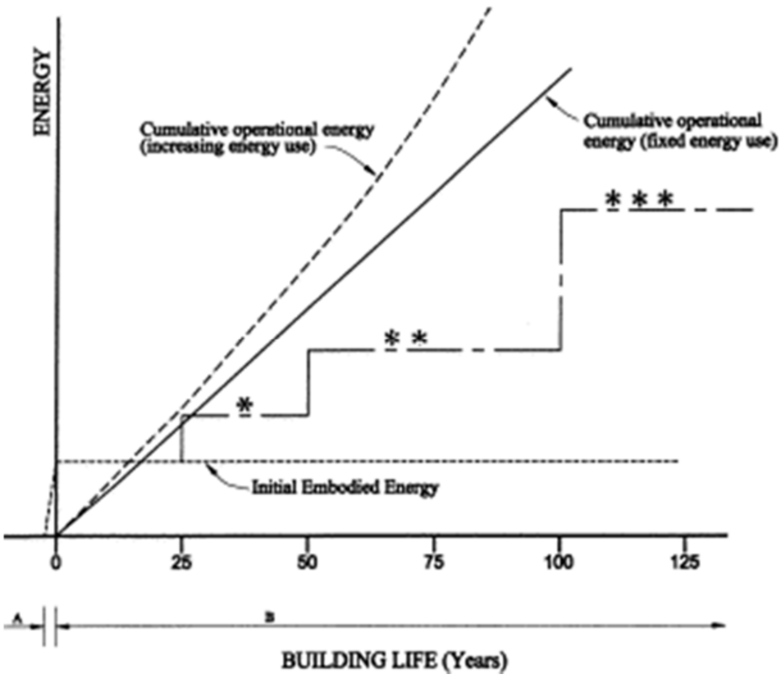


Fig.12 [16]

(which ultimately saves materials), modifying or refurbishing instead of demolishing or adding, salvaging materials from demolition of existing buildings and construction wastes are being reused or recycled, and using locally sourced materials (which includes materials salvaged on site) to reduce transport. [19] Both forms of conservation, operational and embodied, must be taken into consideration when implementing strategies for buildings, old and new. Additionally, better methods for calculating embodied energy need to be put in place. Researching embodied energy analysis reveals there exists no concurrent set of standards that can address the problems of embodied energy calculation, where there is a strong need to develop a protocol or standard that can be utilized for embodied energy analysis to implement into current building construction. [20]

5D. Evaluating Conservation Cost and Per Unit Energy Savings

Energy use is a widely used measure of the environmental impact of buildings. The construction industry's current environmental practices, such as environmental selection of building materials, eco-labeling, and green building assessment, depend mainly on the results of Life Cycle Energy Analysis (LCEA) of buildings. While embodied energy analysis plays an integral part of the process of LCEA, operational energy is just as critical to consider. In fact, operational energy, when reviewed through a life cycle energy analysis, will tend to be much larger than the embodied energy after the same amount of time. [20]



The present preoccupation with buildings lower first costs reveals a disregard for sustainability when considered from a building life cycle perspective. Studies have emphasized the importance of both the operational and embodied energy attributable to buildings over their lifetime. The method of assessing lifetime building energy is known as life-cycle energy analysis. With the target of the Kyoto obligations necessitating the quantification of greenhouse gas emissions at national levels, it appears to be increasingly probable that analyses of this kind will increase in future use. If conducted in terms of primary energy, such analyses will often directly reflect greenhouse gas emissions, with the exception of a few processes which involve significant non-energy related emissions, such as cement manufacturing. A Life-Cycle Assessment would allow for inclusion of these issues as well as including other environmental parameters,

Fig.13 [21]

However, this would most likely include a corresponding decrease in system boundary completeness. Hence, energy efficiency and other environmental strategies should be prioritized on a life-cycle basis. [22] Production and consumption of energy have both social and environmental impacts - energy conservation assists in avoiding these impacts. Prevention is better than countermeasure.

> "Nothing is cleaner than the BTU or kilowatt hour of energy that you don't need, don't consume, and therefore that doesn't need to be produced or generated" [23]

Energy efficiency is commonly perceived to be cost effective and is often portrayed as the lowest-cost utility resource available. Many U.S. states are currently establishing aggressive energy efficiency goals and policies which are likely to require significant increases in future funding. The success of these programs relies in part on the assurance that programs are indeed being run cost-effectively. The American Council for an Energy-Efficient Economy (ACEEE) reviewed the cost-effectiveness results from nine leading states in 2004. This study focused on the reported costs of "saving" kilowatt-hours (kWh) through utility ratepayer-funded energy efficiency programs; the reported utility Costs of Saved Energy (CSE) ranged from \$0.023 to \$0.044 per kWh, with respects to a median value of 3 cents/kWh. The study additionally expands that assessment, and finds the energy efficiency programs from recent years in 14 states have utility CSEs ranging from \$0.016 to \$0.033 per kWh, with an average cost of \$0.025 per kWh.

With these costs of saved energy, energy efficiency is appears to be the least costly energy resource option available for utility resource portfolios. A kilowatt-hour saved through energy efficiency improvements is easily one-third or less the cost of any new source of electricity supply, whether conventional fossil fuel or renewable energy source. Beyond these results, it's also observed that states and utilities have developed a range of energy efficiency program designs and evaluation techniques. Using more standardized reporting methods such as life cycle costs analysis, could provide many advantages, like allowing easier comparisons between states and programs. [24]

A life cycle cost analysis examines and weighs the costs of a measure over its lifespan. It can be used to compare the costs of an existing system over a retrofitted one, hence demonstrating the benefits of a retrofit measure in a more comprehensive method than simple payback. It can also be used to compare two or more retrofit options. The considerations for a LCCA are as follows:

- Initial Costs, Purchase Acquisition, Construction Costs
- Fuel Costs
- Operation, Maintenance, and Repair Costs
- Replacement Costs
- Residual Values, Resale or Salvage Values or Disposal Costs
- Finance Charges, Loan Interest Payments
- Non-Monetary Benefits or Costs

The benefits and costs category shown above allows life cycle cost analysis to consider a wide range of other factors. As an example; a lighting retrofit might save energy and energy dollars plus improve safety, where the safety improvement is

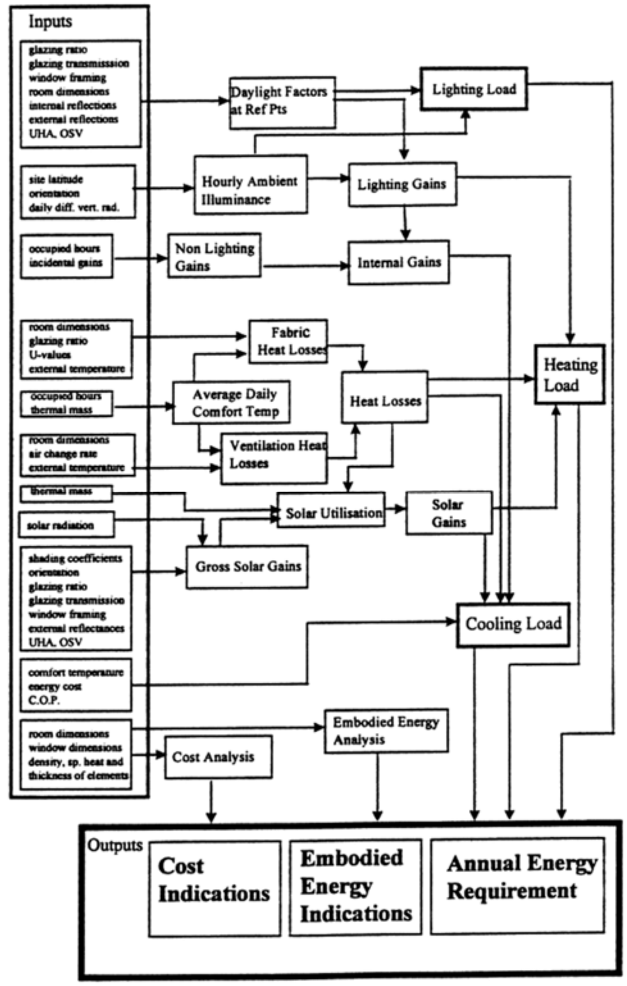


Fig.14 [21]

very important but not easily quantified or dollar value. In a similar case, an HVAC retrofit might save energy and energy dollars plus improve comfort and indoor air quality. This can result in people being happier, healthier and perhaps more productive, important factors not easily quantified or monetized. Additionally, with LCCA, you can also consider altruistic factors, like societal or environmental impacts that typically wouldn't figure otherwise into your costs versus savings calculations. Here, an example might be the impact of a measure on climate, local air pollution, or noise. [25]

The LCCA's purpose is to estimate the overall costs of project alternatives and to make an informed selection for the design that ensures the building will provide the lowest overall cost of ownership consistent with its quality and function. A LCCA should be performed early in the design process while there is still a chance to refine the design to ensure a reduction in life-cycle costs (LCC). The first and most challenging task of a LCCA is to determine the economic effects of alternative designs of buildings and building systems and subsequently quantify these effects and express them in dollar amounts. After identifying all costs by year and amount and discounting them to present value, they are added to arrive at total life-cycle costs for each alternative:

LCC=I + Repl — Res + E + W + OM&R + O
LCC = Total LCC in present-value

(PV) dollars of a given alternative
I = PV investment costs (if incurred at base date, they need not be discounted)
Repl = PV capital replacement costs
Res = PV residual value (resale value, salvage value) less disposal costs
E = PV of energy costs
W = PV of water costs
OM&R = PV of non-fuel operating, maintenance and repair costs
O = PV of other costs (e.g., contract costs for ESPCs or UESCs)

For example, using a LCCA, an assessment of typical initial building costs over a 30 year period, shows a typical breakdown of where design and construction are approximately just 2% of the total, while operations and maintenance costs equal 6%, and personnel costs equal 92%. [26]

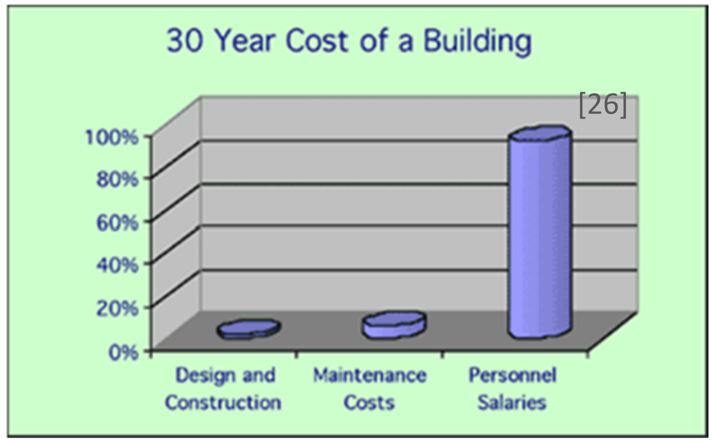


Fig.15 [26]

Typically, integrating sustainable building practices into the construction of buildings is an investment with a good return. In a comprehensive analysis of the financial costs and benefits of green buildings, it was found that a minimal upfront investment of about 2% of construction costs typically yields life cycle savings of over ten times the initial investment. For example, an initial upfront investment of up to $100,000 to incorporate green building features into a $5 million project would result in a savings of at least $1 million over the life of the building, which is conservatively assumed to be 20 years. [27]

In order to compare the costs of efficiency measures and programs against supply side resources, one must take care to create truly comparable measures. One of the most common and useful measures is the cost of saved energy (CSE). A recent study done by Synapse Energy, an energy company based in MA, undertook an extensive review of numerous utility programs from across the United States in order to explore the empirical relationship between the cost of saved energy per kWh saved and the program of first year energy savings as a percentage of annual energy sales. The equation for CES is as follows:

Cost of Saved Energy (in $/kWh) = (Cx10^6) x (Capital Recovery Factor)/(Dx10^3)
Capital Recovery Factor = [A*(1+A)^(B)] / [(1+A)^(B)-1]
Where:
A = Discount rate
B = Estimated measure life in years
C = Total program cost in millions of dollars
D = Incremental annual MWh saved that year by the energy efficiency program

It was found in the study the CSE tends to decrease as energy savings increase relative to annual energy sales. This finding is contrary to the idea of an energy efficiency supply curve that is often constructed to estimate economic potential of energy efficiency measures. These supply curves generally indicate the CSE increases as energy savings increase, much like a generation supply curve would. A typical view expects that the CSE should increase as more of the energy savings potential is tapped.

Energy-efficiency supply curves (CSCs) are often developed for use in energy planning studies and policy analysis. These curves are presented with steps that increase as one moves along the horizontal axis from left to right, along the line of the increasing energy savings. A CSC analysis is a useful tool for comparing the relative costs of energy efficiency measures and for understanding the aggregate potential for cost effective energy efficiency that is available up to any given CSE level. One drawback to CSCs is they are generally constructed in a manner that is limited to demonstrated and currently well understood measures and programs. They may infer increased market share for advanced technologies, but rarely reflect true technological or institutional improvement per time. In contrast, analysts of fossil fuel supply do not limit their analyses to proven resources, but routinely include reserves that are described as "undiscovered," "possible," or "prospective".

Additionally, a CSC analysis can lead to an assumption that energy efficiency programs must match the conservation supply curve where the greater the amount of savings, the greater the program cost. However, it's important to understand that CSEs for programs are expected to differ from CSEs for technologies that underlie CSC analysis for several reasons. The immediate fact is the energy efficiency program costs typically cover a substantial fraction of efficiency's incremental costs and resultantly fluctuates due to many factors such as year, utility, sector, type of program, and size of program. Utility efficiency programs are often composed of various measures that target each sector, including the low-income, residential, and commercial, and industrial sectors. Thus, the overall cost of saved energy for the program is always the weighted average cost of saved energy through a program of various measures.

Figure 2. Illustrative Energy-Efficiency Supply Curve

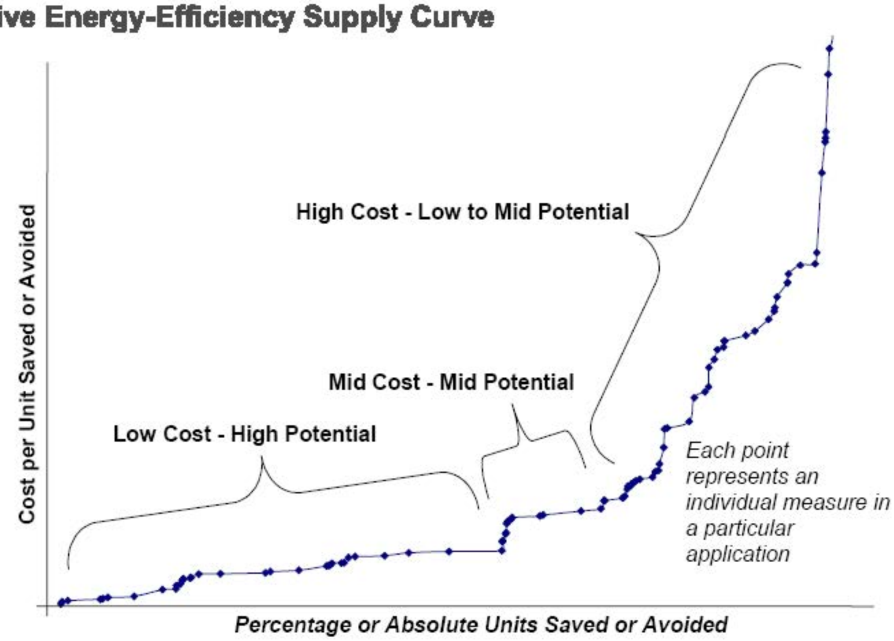


Fig.16 [25]

The CSE is simply the equalized net cost of realizing the efficiency improvement divided by the annual savings in gigajoules *(GJ)*, kilowatt-hours *(kWh)*, or million British thermal units *(MBtu)*. Calculating the CSE provides a cost-effectiveness measure that can be compared to the cost of supply options. The emission savings from energy efficiency are similar to those of renewable energy. The net cost of emission reductions from efficiency and renewable sources depends on the difference between these clean alternatives and the fossil energy supplies they replace. Because energy savings from efficiency programs often cost less than the supply resource they replace, the net cost of some of the resulting emission reductions can be negative. [28]

The cost of energy efficiency typically is all or mostly an initial cost that comprises the increase in capital cost for the high efficiency technology and the associated design, program, or administrative costs. In this case, CSE is: CSE = Capital Cost * CRF / Annual Energy Savings, where CRF = Capital Recovery Factor; the ratio of a uniform annual value and the present value of the annual stream, and it depends on the discount rate and the time horizon considered. Per an example provided by Joel Swisher from the Rocky Mountain Institute; an office lighting upgrade with a net capital cost premium of $2,000 saves about 2 kW of power in a system that operates 5,000 hours per year. The annual energy saving is 10,000 kWh and, assuming a discount rate of 9% and 15-year time horizon *(CRF = 0.125)*, the CSE is: CSE = $2,000 * 0.125 / 10,000 = $0.025/kW. [29]

Buildings consume a vast amount of energy during the life cycle stages of construction, demolition, use and end-use. End-use conservation has traditionally been underestimated by energy policy for society, the environment, and employment. However, end-use energy conservation has great power because units of energy saved at the point of use can save many times that amount of energy when the inefficiencies of energy production and distribution are taken into account. [25]

Conclusion

Both the embodied, as well as operational, energy of a building are important. Studies have discussed the growing significance of embodied energy, as a larger number of buildings are becoming energy efficient and energy independent over time. Embodied energy is also a genuine indicator of greenhouse gas emissions, and hence, could be used to assess environmental impacts. However, the current state of research is plagued by a lack of accurate and consistent data and standard methodology. There's a need to develop an embodied energy protocol that could help streamline the analysis process. There are factors that are promising for creating visibility and development towards an embodied energy protocol; such as the increased use of more durable and recycled materials where the durability of the material is not compromised, and the design inclusion of more appropriate building sizes and more adaptability and deconstruction uses as part of program strategies for longer building lifespans. Other opportunities include substituting low energy intensity materials for high energy intensity materials, reducing construction waste, reusing products, and implementing a framework for energy end-use efficiency.

Energy is part of the broader sustainability problem, which also includes resource depletion, pollution from manufacturing and transportation, together with social and economic inequities. However, energy is currently an important parameter to optimize because of its national and global significance in gross terms. By widening the system boundary of the problem, counterintuitive opportunities for the development of energy conservation and environmental impact strategies can be identified. Furthermore, in general environmental terms the relatively high importance of the initial embodied energy of a building in a temperate climate, as indicated here, may suggest that new construction is not always the best solution. Renovation of an existing building may offer considerable embodied energy and financial savings, with the opportunity to provide equal amenity and perhaps improved efficiency. For new buildings, design flaws such as redundant structure, inefficient planning and circulation, and ineffective shading devices and similar features present opportunities for developing optimization strategies.

Greater consistency is needed in reporting both costs and energy savings and encourages energy efficiency programs to coordinate their reporting strategies to achieve more accessible information comparisons between states and programs. With such strong current results, and in view of the many other environmental and job creation benefits, it is poignant right now to see government organizations, regulators, and utilities supporting the creation and expansion of energy efficiency programs, and increasingly viewing energy efficiency as their first choice of energy conservation.

6. REFERENCES

[1] Belzer, DB. United States. Department of Energy. Energy Efficiency Potential in Existing Commercial Buildings: Review of Selected Recent Studies. Virginia: Pacific Northwest National Laboratory

[2] "Energy Efficiency in Buildings ." World Business council for Sustainable development. (2007): n. page. Print.

[3] Olgay, Victor. Design With Climate . 1st. Print.

[4] http://ecowood.greenplank.eu/definition-of-embodied-energy_140_term.html accessed November 16th, 2012

[5] "Low E storm windows" NAHB Research center, Building Systems. http://www.toolbase.org/Building-Systems/Windows/low-e-windows accessed November 16th, 2012

[6] Image: Energy efficiency in buildings [see reference 2]

[7] "High performance HVAC" WBDG whole building design guide, National institute of building sciences by Carl Ian Graham http://www.wbdg.org/resources/hvac.php accessed November 16th, 2012

[8] Building Energy Efficiency U.S. Congress, Office of Technology Assessment, OTA-E-518 (Washington, DC: U.S. Government Printing Office, May 1992).

[9] "Energy Efficiency" Energy, European Commission http://ec.europa.eu/energy/efficiency/index_en.htm accessed November 16th, 2012

[10] "Embodied energy in buildings: A review". Ralph Horne, Trivess Moore – 2008. http://www.airah.org.au/imis15_prod/Content_Files/MelbForum/MelbForumJun08_RH.pdf. Accessed December 7, 2012

[11] http://www.census.gov/construction/c30/c30index.html. Accessed December 7, 2012

[12] http://en.wikipedia.org/wiki/Embodied_energy. Accessed December 9, 2012

[13] "Sustainable Homes: Embodied Energy in Residential Property Development". http://www.sustainablehomes.co.uk/Portals/63188/docs/Embodied%20Energy.pdf. Accessed December 7, 2012

[14] http://www.yourhome.gov.au/technical/fs52.html. Accessed December 7, 2012

[15] "Measures of Sustainability". http://www.canadianarchitect.com/asf/perspectives_sustainibility/measures_of_sustainablity/measures_of_sustainablity_embodied.htm. Accessed December 6, 2012

[16] "Renewable and Sustainable Energy Reviews". Manish K. Dixit, Jose L. Fernández-Solís, Sarel Lavy, Charles H. Culp. http://faculty.arch.tamu.edu/slavy/Publications/Dixit_et_al_2012.pdf.

[17] "Differential Durability, Building Life Cycle and Sustainability". Ted Kesik, Ivan Saleff. 2005. http://www.daniels.utoronto.ca/files/Kesik_Saleff_CCBS_T2005.pdf.

[18] "Embodied Energy and Historic Preservation: A Needed Reassessment". Mike Jackson, 2005. http://www.ironwarrior.org/ARE/Materials_Methods/EmbodHP.pdf.

[19] http://www.yourhome.gov.au/technical/fs52.html. Accessed December 8, 2012

[20] http://jeancarassus.zumablog.com/images/2128_uploads/___Dixit.pdf. Accessed December 8, 2012

[21] image. http://www.sciencedirect.com/science/article/pii/S0360544201000615. Accessed December 7, 2012

[22] "Life-cycle Energy Analysis of Buildings: a Case Study". Building Research & Information (2000) 28(1), 31-41. Roger Fay, Graham Treloar, Usha Iyer-Raniga. http://eprints.utas.edu.au/8219/2/LIfe-cycle_energy_analysis_of_buildings-_a_case_study.pdf.

[23] http://www.aashe.org/book/export/html/3212. Accessed December 7, 2012

[24] "Saving Energy Cost-Effectively: A National Review of the Cost of Energy Saved Through Utility-Sector Energy Efficiency Programs. Katherine Friedrich, Maggie Eldridge, Dan York, Patti Witte, and Marty Kushler, 2009. http://dandelion-patch.mit.edu/afs/athena.mit.edu/dept/cron/project/urban-sustainability/Energy%20Efficiency_Brendan%20McEwen/LG%20EE%20Policy%20Sectors/Costs/Friedrich%20et%20al%202009%20-%20EE%20Costs.pdf.

[25] http://www.aashe.org/wiki/cool-campus-how-guide-college-and-university-climate-action-planning/51-energy-conservation-and. Accessed December 7, 2012

[26] "Life-Cycle Cost Analysis (LCCA)" Sieglinde Fuller, 2010. National Institute of Standards and Technology. http://www.wbdg.org/resources/lcca.php

[27] "The Costs and Financial Benefits of Green Buildings" Kats, Greg, 2003.
http://www.calrecycle.ca.gov/greenbuilding/design/costbenefit/report.pdf

[28] "Costs and Benefits of Electric Utility Energy Efficiency in Massachusetts" Doug Hurley, Kenji Takahashi, Bruce Biewald, Jennifer Kallay, and Robin Maslowski, 2008. http://www.synapse-energy.com/Downloads/SynapseReport.2008-08.0.MA-Electric-Utility-Energy-Efficiency.08-075.pdf

[29] http://kauaian.net/blog/?p=431. Accessed December 8, 2012

[30] Realizing the potential of energy efficiency: Targets, Policies and measures for G8 countries
<http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&ved=0CDAQFjAA&url=http%3A%2F%2Fwww.globalproblems-globalsolutions-files.org%2Funf_website%2FPDF%2Frealizing_potential_energy_efficiency.pdf&ei=UAC3UIOFNZS_0QGR8ICgDw&usg=AFQjCNG5uD1meDKqP5xZ1fDxtmqf3H8WzQ&sig2=keJLZXkjNzTIhl4eB_RuRA> [Accessed 28.11.2012]

[31] U.S. Congress, Office of Technology Assessment, Building Energy Efficiency, OTA-E-518 (Washington DC: U.S. Government Printing Office, May 1992).
<www.fas.org/ota/reports/9204.pdf> [Accessed 28.11.2012]

[32] Energy Efficiency in Buildings-Business Realities and Opportunities
<www.c2es.org/docUploads/EEBSummaryReportFINAL.pdf> [Accessed 29.11.2012]

[33] Energy Efficiency Requirements in Building Codes, Energy Efficiency Policies for New Buildings
<www.iea.org/publications/freepublications/.../Building_Codes-1.pdf> [Accessed 07.12.2012]

[34] What is LEED <https://new.usgbc.org/leed> [Accessed 07.12.2012]

[35] Advantages and Disadvantages of LEED <http://en.wikipedia.org/wiki/Leadership_in_Energy_and_Environmental_Design> [Accessed 07.12.2012]

[36] India- Constructing Change Report <http://www.nrdc.org/international/india-constructingchange.asp> [Accessed 07.12.2012]

[39] India Initiative on Climate Change and Clean Energy <http://www.nrdc.org/international/india/> [Accessed 07.12.2012]

[40] Energy Efficiency in Commercial Buildings <http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=29&cad=rja&ved=0CH0QFjAIOBQ&url=http%3A%2F%2Fwww.globalcoolcities.org%2Fwp-content%2Fuploads%2F2011%2F09%2FSeth-Presentation.pdf&ei=uGrHUJOHE6qK0QGnpoCwCA&usg=AFQjCNE6zMil3P-GVmCUL2Yg_DLiT8mhuA&sig2=V4hP4EtglbsR2mI-nRKWqA> [Accessed 08.12.2012]

[41] Energy Efficiency India: Fact Sheet <http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=4&cad=rja&ved=0CEMQFjAD&url=http%3A%2F%2Fwww.institutebe.com%2FInstituteBE%2Fmedia%2FLibrary%2FResources%2FEnergy%2520Efficiency%2520Indicator%2F2012-EEI-India-Fact-Sheet.pdf&ei=4IDHUMzMErSs0AHUoYGYAQ&usg=AFQjCNGuML2T1Fm1KG3moezly-uS_XmmVA&sig2=mxwgwv0KAYf3SG88GfyHLQ> [Accessed 08.12.2012]