

Energy Implication of Sustainable Building Design

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ABSTRACT: Buildings in the United States and China account for about 40% and 27%, respectively, of their total primary energy consumption. In order to reduce the energy demand, green building design and construction seem rather helpful. This paper gives a few examples of such design and construction in the two countries. The examples are (1) Donald Bren Hall Building, USA, (2) Twenty-River-Terrace apartment building, USA, (3) Living laboratory at Purdue University, USA, (4) Library of Jinan Transportation College, China (5) Cave Dwellings in North Central China, and (6) Low Energy Demonstration Building at Tsinghua University, China. These buildings used advanced technologies for cooling and heating, indoor air quality, daylighting and artificial lighting, and acoustics. Furthermore, they used recycled and low emission materials and conserved water to make them also environmental friendly. The results show that the energy demand in those buildings is at least 30% lower than that in conventional ones. However, there are barriers to be overcome in order to significantly increase green building design and construction, such as how to use technical design tools and to reduce first costs. Green building design and construction will need time to gain their popularity. Therefore, green buildings will only moderately slow down the increase of energy demand in buildings in the next two decades.

Keywords: building, technology, green, USA, China

1. INTRODUCTION

Our blue planet has 6.678 billions of people. The United States has 304 millions of people or roughly 5% of the world population, which contributes to 25% of the world economy that is the largest [1]. China is the most populated country with 1.33 billions of people or roughly 20% of the world population [1]. At present, China's economy accounts for 6% of the world total. China is the largest economy of the developing countries. At present, the two countries use 23% and 13%, respectively, the world energy [2]. As China has a much faster economy growth, it is projected to use as much energy as the United States in 2015 [2]. The two countries used mainly fossil energy. This imposes serious problems to the world, in terms of global warming due to

greenhouse gas emissions from the fossil energy and pollutants produced in converting the energy. Newspaper USA Today recently reported that the top five polluters in the world in terms of percentage of CO₂ emissions in the world are China (24%), United States (21%), European Union (12%), India (8%), and Russia (6%). China and the United States take the first two spots. Especially the portion of coal used is increasing, which makes pollution control even more challenging. Should the trend continue as "business as usual", the natural resource on the earth will deplete soon, which is definitely not sustainable.

Among the primary energy used, nearly 40% of it is used for buildings in the United States [3] and 27% in China [4]. The increase of fossil energy production may not meet the demand in the world. A better and

more sustainable approach would be through energy conservation. The energy conservation in buildings is a sustainable development. This is because the building industry represents one of the largest enterprises in the United States and in China, and the buildings in general have a usable life of 50 years or more. A small mistake made today in building design and construction would have a lasting impact for generations.

It should be noted that a major part of the energy used in buildings is for the maintenance of a comfortable and healthy indoor environment through Heating, Ventilating, and Air-Conditioning (HVAC) systems. The use of HVAC systems does not necessarily create a healthy indoor environment. Indeed, reports of symptoms and other health complaints related to indoor environments have been increasing. However, the majority of health problems reported in buildings (namely, nonspecific complaints sometimes called the sick building syndrome) cannot be attributed to specific exposures. Available evidence suggests that multiple factors are involved, including indoor air quality; physical conditions such as temperature, humidity, lighting, and noise; and social and/or psychological stressors. Poor indoor environment conditions cost around \$20 to \$160 billion in lost wages and productivity, administrative expenses, and health care in the United States [5].

Therefore, sustainable or green building design by using solar energy, wind, advanced materials and systems has become popular. A number of pioneering architects in Europe have designed many green buildings with considerable success. However, such a design has yet become an industrial norm because of perception of higher costs in construction and difficult to design. As the oil price is surpassing \$140 per barrel and demanding a better indoor environment, the green designs deserve a serious look today.

This paper will first give a few examples of green buildings in both the United States and China. Then the paper will outline some aspects of challenges in designing such buildings. Finally, this paper will discuss the implication of such green buildings on energy.

2. CASE STUDIES OF GREEN BUILDINGS IN THE UNITED STATES

This paper uses three examples from the United States to illustrate the technologies and benefits of green buildings. The first case is an office and laboratory complex on a university campus, the second one is a residential building, and the third one is a green building research facility.

2.1 Donald Bren Hall Building

The Donald Bren School of Environmental Science and Management as shown in Fig. 1 received a Platinum LEEDTM Rating from the United States Green Building Council (USGBC) [6]. The 7743 m² building included offices, laboratories, and seminar rooms. Office spaces surround the courtyard and lab spaces were located in the main building. The Bren building faces to the Pacific Ocean. The technologies used included recycled materials, natural ventilation, daylighting, artificial lighting, energy efficiency, indoor environmental quality, and water efficiency.

For energy related technologies, the office spaces used natural ventilation coupled with mechanical ventilation. Cross ventilation was promoted by having thin building thickness. Operable windows were equipped with sensors that turn off heating when opened.



Fig. 1 Donald Bren Hall Building(courtesy of USGBC)

The courtyard space provided natural shading and therefore cooling during daylight hours. Although windows were located on the east façade, they had been angled to face north, which was a very nice design feature. Concrete walls provided a high thermal mass to store solar energy during the day. This helped to temper the indoor air.

To minimize “heat island” effect, a white roofing system was used. White and light colors were effective in reflecting incident solar radiation, decreasing the amount of solar energy absorbed through the roof.

The building used daylighting; and artificial lighting can be dimmed to achieve desirable lighting level and to save energy. Some other energy saving features were:

- Premium-efficiency motors on all equipment
- Variable-volume pumping systems
- Variable-air-volume laboratory exhaust and supply system
- A photovoltaic system
- Optimal control of exhaust fans for hoods.
- Optimal use of local and campus chillers

Bren Hall surpasses California’s Title 24 requirements for energy efficiency by more than the estimated 31% [6].

2.2 Twenty River Terrace

Located in New York City, Twenty River Terrace used systematically sustainable

design guidelines on cooling, heating, indoor air quality, lighting, building envelope, building materials, water, and renewable energy.

Cooling and heating used a high-efficiency, environmental friendly air conditioning system. The centralized air system filtered air and the operable windows allowed for fresh air and cross-ventilation, which created a high indoor air quality. The use of low-emission materials in construction was also helpful to the air quality. A heat exchanger was used to recover heat from the air to heat water for the apartments. Daylight and occupancy sensors were used to control the lights. High efficiency lights and fixtures saved energy throughout the building. The buildings used high efficient appliances to conserve energy and water. Programmable thermostats, vertical fan coil units, exhaust vents were used further to enhance indoor environmental quality and save energy.



Fig. 2 Twenty River Terrace (Courtesy of DoE)

This 27-story apartment building operated 35% more efficiently than required by the New York State Energy Code [7].

2.3 Living laboratory at Purdue University

Purdue University is planning to construct a new home for Ray W. Herrick Laboratories, as shown in Fig. 3, which will use the new building to develop and assess technologies for high performance buildings. One of the centerpieces is to build a “Living Laboratory” office wing as shown in Fig. 4,

which is designed to have replaceable elements (communications, controls, equipment, façade), reconfigurable air distribution and lighting, and continuous monitoring of systems and occupants. Researchers will be able to use this facility to develop and validate new building systems and components for design sustainable, energy-efficient, and healthy buildings.



Fig. 3 New Ray W. Herrick Laboratories (Courtesy of Flad)



Fig. 4 The living laboratory (Courtesy of Flad)

The new building will also contain a perception-based engineering laboratory that can simulate various indoor environments. One can independently control the lighting, acoustics, air quality, thermal comfort, and vibration.

The Living Laboratory will ensure that technology and environmental control schemes that appear to work well in precisely control laboratory tests or in simulation play out in practice, thus reducing the risk of implementation of this advanced technology. Using the data collected in the highly “sensored” living laboratory it will be possible to investigate the un-modeled system behavior that undercuts projected pay-offs and the data will enable development of models and

technology to address the problems identified. The integration of human response modeling will also ensure the environmental control is optimized for the users of the spaces.

The major technologies to be developed and validated include, but not limited to:

- Architectures for “plug-and-play” comfort delivery
- Architectures and algorithms for “plug-and-play” control
- “Smart” and sustainable equipment
- Building construction elements
- Monitoring
- “Fast” models for comfort, safety, and energy analysis
- Integrated design and operations tools

According to the USGBC, green buildings can lead to 30-70% less energy use, 20% higher test performance for schools, 2.5 days earlier discharge in hospitals, 2-16% productivity increase in offices. As a result, the number of LEED certified buildings is rapidly increasing as depicted in Fig. 5.

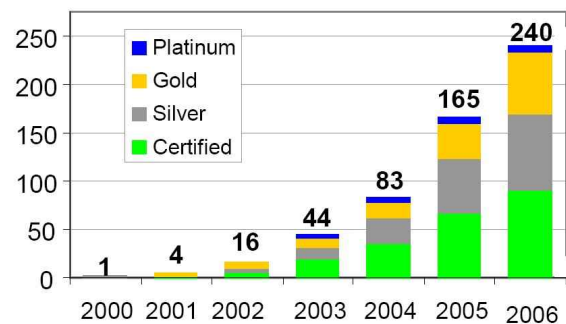


Fig. 5 The increase in LEED certified buildings [9]

Nevertheless, the United States has been lag behind Europe and Japan in green buildings. The main reason could be attributed to relatively inexpensive fossil energy in the past due to its energy policy. For example, in most of the 1990s, the gasoline price was around \$1 per gallon (3.7 liters) that was only 1/4 to 1/3 of the price in Europe and Japan. The cheap energy made no incentive for building owners and tenants

to spend a little bit more money in design and construct green buildings.

In addition, the United States spent in fiscal years 2003-2005 only 0.2% of the federal research and development budget for green buildings (on an average of \$193 million/year), compared with 57.24% for national defense and 23.06% for health [10]. The budget for green buildings is roughly equivalent to only 0.02% of the estimated value of annual U.S. building construction, despite the fact that the construction industry represents 9% of the GDP of the United States [10]. Without adequate research, it is hard to produce concrete evidence to building owners and tenants the benefits associated with green buildings, such as productivity increase.

3. CASE STUDIES OF GREEN BUILDINGS IN CHINA

Similarly, this paper uses three examples from China to discuss the trend of green building design and construction. The buildings selected are a library building on a university campus, a cave residential building, and a living lab.

3.1 Library in Jinan Transportation College

The 15,700 m² of library in Jinan Transportation College shown in Fig. 6 is a sustainable building that is environmental friendly, energy-efficient, and healthy to its occupants [11]. The design aimed at low cost construction, sustainable strategies of land use, energy efficiency, and water conservation.

The building used passive shading, underground duct for precooling, stack ventilation through atriums, daylighting, high performance insulation, and the substitution of cooling tower with the pond water to reduce energy demand.



Fig. 6 Library of Jinan Transportation College (Courtesy of B. Lin)

The passive shading used an external shading wall for the west, recessed vegetation for the east, and fixed exterior shading for the south. The underground duct can pre-cool or pre-heat the air to the building. The building was designed to use stack and cross ventilation in summer. The air induced from the windows or the underground duct was heated by sun at the top of the atrium where it was exhausted. The building used solar energy in the greenhouse to heat it in winter. Daylight can penetrate through the atrium roof and the south glazing to the inner zones that can reduce the artificial lighting. The building used pond water to cool the evaporator of the chillers. The cooling water temperature was significantly lower than the air temperature.

The total energy use in this building was 40% lower than a similar building on the campus.

3.2 Cave Dwellings in North Central China

Loess Plateau in China has an area of about 400,000 km². The climate is dry with abundant solar. Traditional cave dwellings are not nice to live: high humidity in summer and poor air quality, but they are inexpensive to build and rather comfortable in winter.

Liu [12] has improved the cave dwelling design by using sustainable technologies to overcome the problems in old design with

success, as one illustrated in Fig. 7. For example, the new design used two floors instead of one to increase indoor area to meet the high standard of living. The new design used solar heating in winter and stack ventilation in summer. The new dwellings were thermally stable and used no energy for heating or cooling. Daylighting, ventilation, humidity, and air quality in the new cave buildings were significantly improved. More importantly, the new cave buildings retained traditional style and features of the local vernacular dwellings but had some modern flavors.



Fig. 7. New cave dwellings (Courtesy of J. Liu)

Extensive measurements show that the new cave dwellings had an air temperature of 3 K higher than the old ones in winter. The daylighting factor in the new cave dwelling was also higher and the residents were much more satisfied by their indoor environmental quality.

3.3 Low Energy Demonstration Building at Tsinghua University

The 2920 m² office building at Tsinghua University as shown in Fig. 8 has been a living laboratory for the demonstration of low energy building technologies, such as energy conservation and renewable energy utilization.



Fig. 8 Low energy demo building at Tsinghua University (Courtesy of Y. Zhu)

The main technologies used include:

- Double skin façade with controllable shading and hybrid ventilation
- Controllable daylight reflectors and light well
- Raised floor with phase change material for thermal storage
- Brine desiccant system for independent humidity control and solar heat for regenerating the desiccant system
- Stack natural ventilation
- PV panels for electricity generation
- Personnel air-conditioning system

Since it is a demonstration building, not a lot of research has been conducted for the building.

Compared with the West, green building design and construction in China were not on agenda until recently. There have been a number of efforts to build green buildings in China several years ago. The efforts have achieved mixed results. Some have never been built [13] and those built do not have concrete validation of success. Green building design and construction are more expensive in China. A majority of buildings built in China are not energy efficient and environmental friendly.

The Chinese government has noted the long-term consequence of the current design. A lot of efforts have been made to promote energy-efficient buildings. In the 11th national five-year plan (2006-2010), the Chinese government has invested several hundreds of millions of Yuan on energy-

efficiency of large public buildings, renewable solar energy, energy conservation, etc., aiming to reduce energy demand in new large buildings by 50% and in medium and small buildings and dwellings by 40%. The Chinese government investment on building related research is more than that of the U.S. government, although the labor costs in China are lower.

4. BARRIERS TO SUSTAINABLE BUILDING DESIGN

At present, only 6% of new commercial buildings and 5% of new residential buildings in the United States are designed and constructed with some green features [9], despite of the advances and benefits of green buildings. The percentage in China at present is negligible. The major barriers can be summarized as:

First cost versus operating cost: It is believed that green buildings may cost more for design and construction and may save operating cost. Information is rarely conveyed to tenants or buyers on the benefits of green development.

Lack of performance information on green building features: It is a primary concern for many developers and their project financiers. Even if such information is available, it is hard to convince parties concerned that the information is indeed accurate. This is because conflicting results or the lack of one reliable authority on performance often weaken the credibility of existing studies.

Lack of green building design experience and knowledge from architects, engineers, contractors: Green building design and construction are new to many designers and contractors. Green development pioneers may have additional risks in pursuing the effort. It is essential to have right tools for green design, which can be expensive, may need highly skilled designers, or may even not be available.

For example, we have involved in designing energy-efficient buildings in

China. In order to design natural ventilation, our studies used both Computational-Fluid-Dynamics (CFD) program and a multizone airflow network model program. The design of shading and passive solar heating used a lighting analysis program. To estimate the energy efficiency, our investigation used an energy analysis program. In most cases, the data input for one program did not work for another program. It was rather time consuming to construct all the input files. The effort was very significantly. Some advanced tools, such as CFD program, may generate a result that is not reliable. Unless a design is carried out by a major design firm, it would be rather expensive to have such in-house expertise to provide the technical support.

Conflict with standards, codes and regulations: Their use in project evaluation may need to be revisited as they can unintentionally impede green development.

Lack of incentives: So far there are not many incentives to build green. One solution is to adopt LEED system and use the points to calculate financial incentives through tax. Current bidding and awarding process does not encourage green design. Contract is often awarded to the lowest bid regardless of green experience. Many involved in the project are risk averse and prefer a traditional approach.

A lot of efforts are being taken by the USGBC, many cities, and organizations to remedy the problems. But the efforts would need time to streamline the design and construction process.

5. ENERGY IMPLICATION OF SUSTAINABLE BUILDING DESIGN

In both the United States and China, the design of sustainable buildings is just beginning. It will take several decades to make such design a norm for the building industry. Since building has a useful life of 50 years, the existing buildings will have a huge impact on the energy use for several decades to come.

For example, if we assume that green design is creased by 10% per year, about 50% of new constructions in 2030 in the United States will be green ones. Then 10% of the total building stock in 2030 will be green buildings. Those buildings are assumed to be 30% more energy-efficient than existing buildings. The total energy reduced by this effort will be around 3%. The number could be doubled if green measures are applied to retrofit existing buildings. As the total energy demand by buildings in 2030 could be 18% more than that of today [2]. The effort in green building design and construction will only show a significant slow down in the increase trend.

Let us assume that China will take more aggressive approach in green design and construction to increase green buildings from less than 1% at present to 50% in 2030. This assumption is with 20% increase rate per year. Then 6% of the total building stock in 2030 will be green buildings. The energy demand of the green buildings will be reduced by 70% compared with the existing buildings. The total energy saving by this effort in China will be 4%. Again by considering green retrofiting of existing buildings, one would see a moderate trend of slow down in energy demand although the total energy consumption in 2030 could be increased by 55% [1] if business as usual.

Nevertheless, no one should overlook the efforts. This is because the total energy demand at that time in the world will be 40% higher than that of today if no significant measures are taken to reduce the energy demand. If similar efforts could be assumed for the rest of the world, the total energy reduced by green design and retrofiting could reduce 5-10% of the total primary energy used in 2030.

6. CONCLUSION

This paper gives an overview of energy demand by buildings in the United States

and China. Green building design and construction could be used to reduce the energy demand. This paper shows several examples of green design and construction in both the countries. However, there are considerable barriers in green building design and construction. As building has a long life and the increase of green design and construction may not be very rapidly, the green design and construction will only moderately slow down the energy demand by buildings in the next two decades.

REFERENCES

- [1] CIA, 2008. World Fact Book, <https://www.cia.gov/library/publications/the-world-factbook/>
- [2] EIA, 2008. <http://www.eia.doe.gov/>
- [3] EIA, 2005. Annual Energy Review U.S. Department of Energy. DOE/EIA-0384.
- [4] Shen, J.M. 2007. Indoor air quality and health, Refrigerating Technology, 1, 10-14.
- [5] Fisk, W.J. 2000. Health and productivity gains from better indoor environments and their relationship with building energy efficiency, Annual Review of Energy and the Environment, 25, 537-566.
- [6] EPA and DoE, 2004. Laboratory for the 21st century, DOE/GO-102004-1794.
- [7] DoE, 2002. Buildings for the 21st century, DOE/GO-102001-1611
- [8] USGBC, <http://www.usgbc.org/>
- [9] Turner, C, Frankel, M. 2008. Energy performance of LEED® for new construction buildings, Final Report for USGBC, New Building Institute, WA.
- [10] USGBC, 2007. Green Building Research Funding: An Assessment of Current Activity in the United States, <http://www.usgbc.org/>
- [11] Zhu, Y, Lin, B., Yuan B. 2007. Low cost green buildings practice in China: Library of Jinan Transportation College, Proceedings of Sustainable Building Asia SB07, Seoul.
- [12] Liu J., Wang, D., Liu Y. 2002. An instance of critical regionalism: new yadong dwellings in north-central China, Traditional Dwellings and Settlements Review, 13(2).
- [13] Glicksman, L., Lin, J. 2006. Sustainable Urban Housing in China, L. Springer.