GENI Global Energy Network Institute

Skyscraper Green Retrofits Guide


Dec 2011

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Abstract

This paper investigates the ways to retrofit high raise commercial buildings into outstanding sustainable buildings. Looking up in the middle of the busiest cities in the world, we can barely see the sky for the skyscrapers. High rise buildings are cool and modern, but they generate 16 percent of the energy consumption worldwide and 40 percent of the total energy consumptions in the U.S. Carbon dioxide emissions from buildings account for 40% of the total generation of carbon dioxide emissions in the U.S. and cost $100 billion annually. Due to global population growth, more energy will be consumed annually; hence, the tremendous release of greenhouse gases will further increase exponentially with the population. Therefore, reducing gashouse gas emission is an emergency. Some of the smartest architects have begun to craft net-zero building, which has a net zero emission of carbon dioxide. However, most of the busiest cities in the world are already packed with skyscrapers, leaving no space for new development. In the U.S., 72% of floor space belongs to buildings that are over twenty years old (2). This phenomenon makes the value of finding the best ways to retrofit existing buildings more urgent than creating new net zero new buildings.

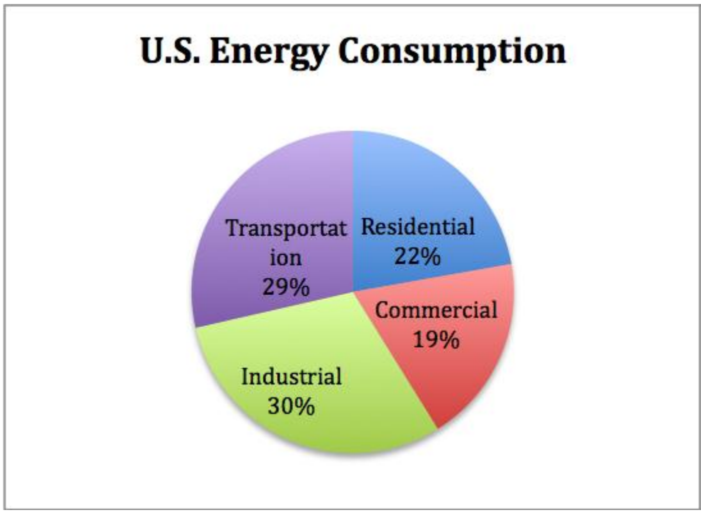

Figure 1. U.S. Energy Consumption by Sector in 2008 [1]

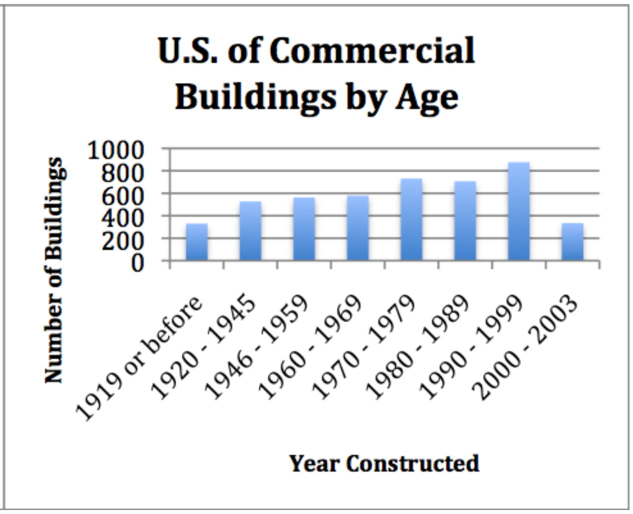

Figure 2. U.S. Commercial Buildings by Age[3]

1. Driving Force

1.1 Funding/Program

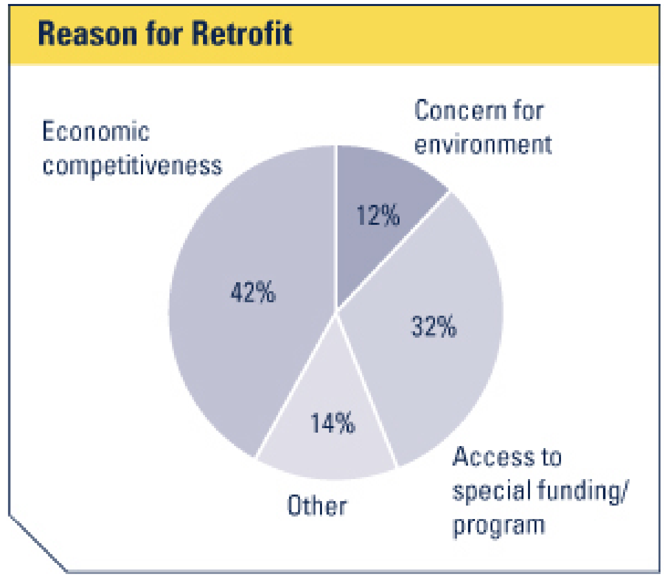

Figure 3. Reason for Building Retrofits in Canada[4]

Not surprisingly, one of the major reasons for building owners to renovate their buildings is the concern for environmental issues. Global warming is no longer just an estimation but an undeniable challenge humans are facing. However, building owners may not dare to go green because of financial concerns. To solve the problem, some utility companies, national, state or county, have initiated financial assistance programs for owners to carry out energy efficiency retrofits for their buildings. Countries like Czech Republics, Canada, U.S., etc. give funding, incentives or tax credits for property owners who do extensive renovations on their buildings. One of the programs in the States, called the Energy Policy Act, gives incentives to residential and commercial building owners who conduct renovations for energy efficiency and sustainability. In 2010, U.S. Vice President, Joe Biden announced the provision of $425 million funding to speed up the energy efficiency building retrofits in the country. Biden also commented on building energy efficient renovation as "a triple win (5)." One win is for the environment due to reduced energy usage, which will significantly lower the greenhouse gas emission annually. Another win is for the energy consumers whose energy bill will be reduced by the retrofit. The last win is for the economy as green jobs will be created (5).

At the same time, some organizations launched programs to give credits to satisfactory energy performance buildings. Consequently, building owners can use the accreditation in their marketing strategies to increase competiveness based on their buildings.

1.2 Introduction of Building Rating Systems

Corporations are progressively aware that the design and operation of their buildings can help cut down more than 24% of energy use and 40% of water use. However, without proper assessment and comparison, it is difficult to know how much corporations need to further reduce their energy use, or how well they have done already. Therefore, green building rating systems have been launched all over the world. The U.S. government and the U.S. Green Building Council have launched the Energy Star and Leadership in Energy and Environmental Development (LEED) respectively to give certifications to up-to-standard sustainable buildings. The first green building rating system -- the Building Research Environmental Assessment Method (BREEAM), was founded in 1990 in the UK. Although BREEAM has existed for more than 20 years, many building owners still go for LEED due to its global corporate policy, which can give their building a more universal recognition than the UK policy based BREEAM (6). Whether it is Energy Star, LEED, BREEAM or Green Star of Australia, these programs are not limited to new buildings. Existing buildings can also earn certificates from these programs by earning enough points through green retrofits. Building owners may have to invest a considerable amount for the initial cost; however, case studies have shown that investments could be paid back in about 2 to 3 years by energy cost reduction (7). In addition to the reduction in energy cost, some building owners would use the advantage of the proven increase in occupant's satisfaction to attract bigger companies.

Sustainable Building Rating Systems	Development Basis
BREEAM (Building Research Establishment's Environmental Assessment Method)	Original
BREEAM Canada	BREEAM
BREEAM Green Leaf	BREEAM, Green Leaf™
Calabasas LEED	LEED®
CASBEE (Comprehensive Assessment System for Building Environmental Efficiency)	Original
CEPAS (Comprehensive Environmental Performance Assessment Scheme)	LEED®, BREEAM, HK-BEAM, IBI
Earth Advantage Commercial Buildings (Oregon)	Undisclosed
EkoProfile (Norway)	Undisclosed
ESCALE	Undisclosed
GBTool	Original
GEM (Global Environmental Method) For Existing Buildings (Green Globes) – UK	Green Globes Canada
GOBAS (Green Olympic Building Assessment System)	CASBEE, LEED®
Green Building Rating System – Korea	BREEAM, LEED®, BEPAC
Green Globes Canada	BREEAM Green Leaf
Green Globes™ US	Green Globes Canada
Green Leaf Eco-Rating Program	Original
Green Star Australia	BREEAM, LEED®
HK BEAM (Hong Kong Building Environmental Assessment Method)	BREEAM
HQE (High Environmental Quality)	Undisclosed
iDP (Integrated Design Process)	Original
Labs21	Original
LEED® (Leadership in Energy and Environmental Design)	Original
LEED Canada	LEED®
LEED India	LEED®
LEED Mexico	LEED®
MSBG (The State of Minnesota Sustainable Building Guidelines)	LEED®, Green Building Challenge '98, and BREEAM
NABERS (National Australian Built Environment Rating System)	Undisclosed
PromisE	Undisclosed
Protocol ITACA	GBTool
SBAT (Sustainable Buildings Assessment Tool)	Original
Scottsdale's Green Building Program	Undisclosed
SPiRiT (Sustainable Project Rating Tool)	LEED®
TERI Green Rating for Integrated Habitat Assessment	Original
TQ Building Assessment System (Total Quality Building Assessment System)	Original

Figure 4. Sustainable Building Rating System Throughout the World[8]

1.2.1 Energy Star

The Energy Star Portfolio Manager is a rating system launched in the U.S. by the United State Environmental Protection Agency. The program started by labeling energy efficient products, including light bulbs, computers, refrigerators and heat pumps etc. Thus, consumers can figure out which appliances work more efficiently than average. The Energy Star Program has also developed an energy performance rating system for different types of buildings, including K-12, commercial, hospitals etc. To achieve the Energy Star Recognition, evaluators need to input the building's energy data onto the EPA online tool, Portfolio Manager, to determine if it is qualified to be an Energy Star building. Commercial buildings that earn the Energy Star must perform in the top 25 percent among the same type of buildings in the nation. The buildings are also required to be verified by a licensed professional engineer or architect annually (9). Energy Star Portfolio Manager can recognize building energy efficiency accurately; therefore, another green building rating system, LEED, has incorporated Energy Star energy performance rating as one of their energy reduction standards.

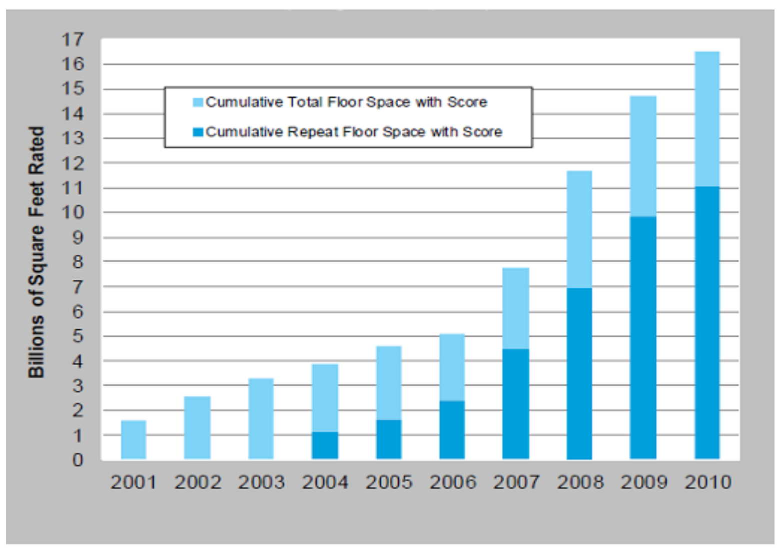

Figure 5. Floor Space with Energy Star Score[10]

1.2.2 Leadership In Energy and Environmental Design

Leadership in Energy and Environmental Design (LEED) is a green building rating system launched by the U.S. Green Building Council in 1998. Similar to Energy Star, LEED is another program that certifies up-to-standard buildings through a point system. Regardless of building types, as long as the building fulfills the minimum requirements of its corresponding rating system, the building is eligible participate in LEED. After knowing the project is eligible to join LEED, the project team needs to ensure the building can achieve the minimum requirements of the categories in the rating system. Otherwise, none of the points in that category could be earned. One thing that makes LEED harder to be obtained than Energy Star is that LEED concerns not only the building's energy performance, but also the other aspects that the building affects. For instance, LEED has a section for Indoor Environmental Quality, which serves to assure the air and light quality inside the building is maintained well enough for occupants to use the building comfortably. Owners may fulfill this category by increasing ventilation, purchasing sustainable cleaning products, or installing air filters. However, upgrading air filters or ventilators will increase energy usage, hence, lowering the score in the Energy and Atmosphere category. As obtaining a LEED certification requires a good balance between energy, water and carbon dioxide reduction as well as occupancy comfort, LEED certification is known as one of the most realistic indications of satisfactory green buildings. Though participating in LEED costs more for a longer time than going for Energy Star recognition, many building owners still choose LEED because of its well-rounded measurements and the additional guarantee of occupants' comfort improvement.

2 Potential Ways to Retrofit Buildings

2.1 Lighting

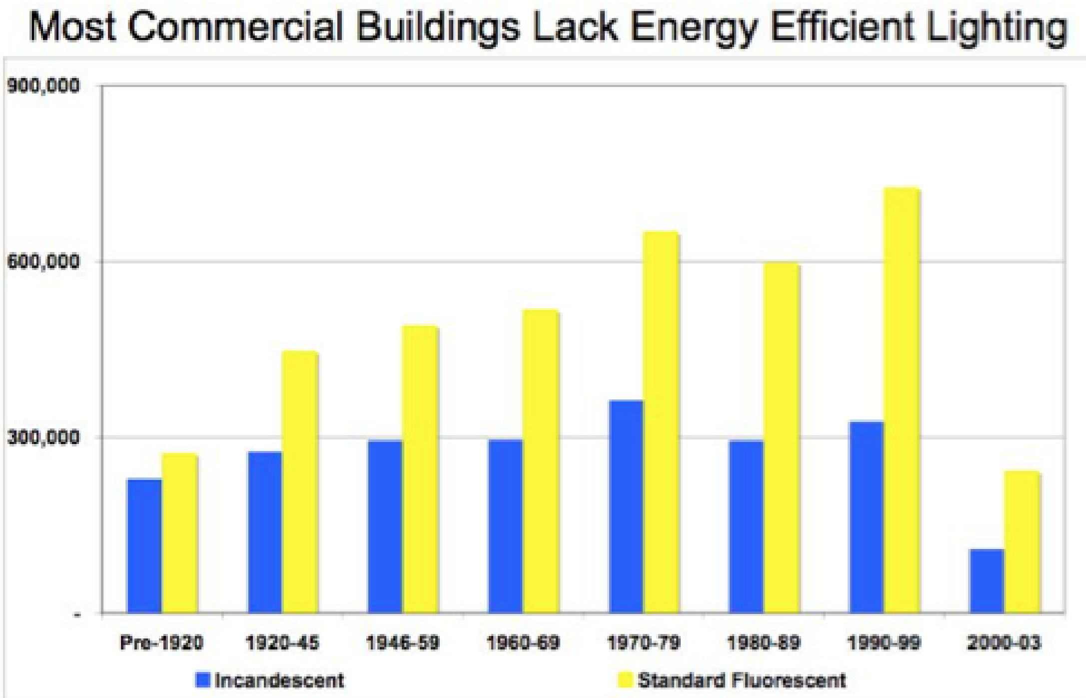

Figure 6. Lighting Fixtures of Commercial Buildings by Age[11]

Among all the methods, the most common retrofit type that building owners perform is lighting retrofits. One of the reasons is because a lot of commercial buildings do not have energy efficient lighting. Therefore, lighting retrofits can help reduce a huge amount of energy use. Also, lighting retrofits are some of the easiest retrofits of a building. After carrying out an audit to figure out upgrade opportunities, owners can simply change the old fluorescent lighting fixtures into Energy Star benchmarked fixtures, for example, T5 or T8 high bay fixtures (12). Another lighting option that owners can upgrade is to add a timer or occupancy sensor on the fixtures that are only used occasionally, allowing the lights to be turned off automatically when not in use. Owners can also add a dimmer or photo-sensor for the fixtures so that when natural night is available, the photo-sensors will adjust the brightness of the fixtures to reduce unnecessary lighting. Researchers have shown that simply by updating all the lighting fixtures the lighting level of the fixtures can increase while reducing up to 70% of the total energy use (12). Moreover, if adequate windows are added to increase the use of natural sunlight, it would further cut energy use in lighting. However, setting up windows to increase the amount of natural light reaching the work place may increase unwanted heat loss or gain, which may jack up the energy needed in space heating and cooling. Thus, a good balance between the two is needed to achieve energy efficiency.

2.2 Insulation

Most of the energy used in buildings goes to space heating and cooling. Therefore, reducing the unwanted heat gain or loss of the building is very important in reducing energy load. If the insulation is not good enough, unwanted heat will be gained during summer and lost during winter through the building envelope, causing extra energy use to heat or cool the building. Though the area of the windows may only take up to 15 to 25 percent of the whole building envelope, it can account for 40 to 70% of the total heat loss of the building (13). The good news is that upgrading insulation of windows is a cost effective retrofit. In the Empire State building case study, upgrading insulation of windows alone helped them save $410k per year (31). There are varies ways to enhance insulation of the windows. One way is by replacing the existing windows into low U-factor windows and adding weather-stripping on windows to prevent air leakages. A low U-factor window has a low rate of heat loss through conduction; hence it can reduce unwanted heat gain or loss (13). In a typical building, most of the windows are single pane windows, which behave like a glass coffee cup in which our hands feel the heat when the coffee is poured into the cup. That happens because the cup, as well as the single pane window, are very good conductors that transfer heat rapidly through conduction, convection and radiation. To better insulate the building, owners can replace the single pane windows with double pane windows, i.e., saving a small space between the two glasses of the window. Gas with a bad heat transfer coefficient fills the space inside the windows, which helps to reduce rate of heat transfer between the windows and the outside air. In addition, owners can add a film of low emissivity coating on the windows to further lowering heat transfer between the envelope of the building and the ambient air (13). Owners should also pick window frames that have a low U-factor to maximize the insulation of windows.

Figure 7. Double Pane Window[14]

Beside windows, heat loss through the wall is also a key. Therefore, an energy efficiency scale of materials, called R-value, has been developed to let the consumer better choose insulated materials for their buildings' envelope (13). However, this kind of insulation upgrade is rather unpopular due to the extensive cost and time required for the work. Though heat loss through doors is not so significant, an inexpensive upgrade is possible to make insulation even better. A simple way to upgrade doorway insulation is to replace the single door entrance with a two-door entrance plus weather-stripping. The mechanism works the same as having a double pane window instead of single pane window. In addition, painting the building a light color can also help reduce unwanted heat gain for the building, because it does not absorb as much radiation as a darker color. Insulation of the building can highly affect the energy load of the HVAC system of the buildings, thus insulation is crucial in energy efficiency.

2.3 HVAC

HVAC stands for heating, ventilating and air conditioning. It is a vital system for occupancy's comfort. If a building has a good insulation level, the load of the HVAC system can be vastly reduced. Yet, through maintenance and upgrades, the efficiency of the HVAC system can be improved to minimize the impact on the environment.

The best thing about reducing energy use through maintenance is that it is a cost effective method. Owners can simply clean the air filters, ventilators, boiler tubes etc. and make sure all the HVAC equipment is sealed so that heat transfer is only effective where its wanted. Calibration can also be carried out and corrected as needed so that unneeded energy use will be trimmed down.

Besides the impact of energy use on the environment, ozone depletion potential of refrigerants is very crucial to human health. Ozone is a protective layer of the earth's atmosphere that absorbs the highest energy of the sunlight, UVC. If the there were no ozone layer present, humans would not be able to live on earth. As the traditionally used refrigerants have high ozone depletion potential, the Montreal Protocol has banned the production of CFCs and is phrasing out HCFCs. However, there is a dilemma in choosing replacement for CFCs and HCFCs. As shown on Figure 8 below, most of the refrigerants with a low GWP (Global Warming Potential) have a relatively high ODP (Ozone Depletion Potential). A refrigerant with low GWP is more efficient, which would cost less energy use and thus emit less greenhouse gases; however, refrigerants with high ODP have a stronger impact on the ozone layer during leakage. Fortunately, as we can see on Figure 8, natural refrigerants not only have zero ODP but also a negligible GWP. Therefore, undoubtedly, they are the best refrigerants for the environment. Numerous industrial buildings have already been using natural refrigerant for air conditioning. Though there are not a lot of commercial buildings making use of natural refrigerant yet, the number has been increasing in recent years.

Refrigerant	ODP	GWP	Building Applications
Chlorofluorocarbons			
CFC-11	1.0	4,680	Centrifugal chillers
CFC-12	1.0	10,720	Refrigerators, chillers
CFC-114	0.94	9,800	centrifugal chillers
CFC-500	0.605	7,900	centrifugal chillers, humidifiers
CFC-502	0.221	4,600	low-temperature refrigeration
Hydrochlorofluorocarbons			
HCFC-22	0.04	1,780	air conditioning, chillers,
HCFC-123	0.02	76	CFC-11 replacement
Hydrofluorocarbons			
HFC-23	$< 4\times10^{-4}$	12,240	ultra-low-temperature refrigeration
HFC-134a	$< 1.5\times10^{-5}$	1,320	CFC-12 or HCFC-22 replacement
HFC-245fa	$\sim10^{-5}$	1,020	Insulation agent, centrifugal chillers
HFC-404A	$\sim10^{-5}$	3,900	low-temperature refrigeration
HFC-407C	$\sim10^{-5}$	1,700	HCFC-22 replacement
HFC-410A	$< 2\times10^{-5}$	1,890	air conditioning
HFC-507A	$\sim10^{-5}$	3,900	low-temperature refrigeration
Natural Refrigerants			
CO_2	0	1.0	
NH_3	0	0	
Propane	0	3	

Figure 8. Table of ODP and GWP of refrigerant[16]

Undeniably, using natural refrigerants still has its drawbacks. For instance, although ammonia has zero ODP and zero GWP, it is toxic, flammable and its installation price could be up to 250% more than for a hydrofluorocabon refrigerant unit (17). As for hydrocarbon, it is non-toxic but highly flammable. Thus, modification of the air conditioning system may be needed if a natural refrigerant is used. Owners will also have to decide which refrigerant best matches their building demand.

2.4 Appliances

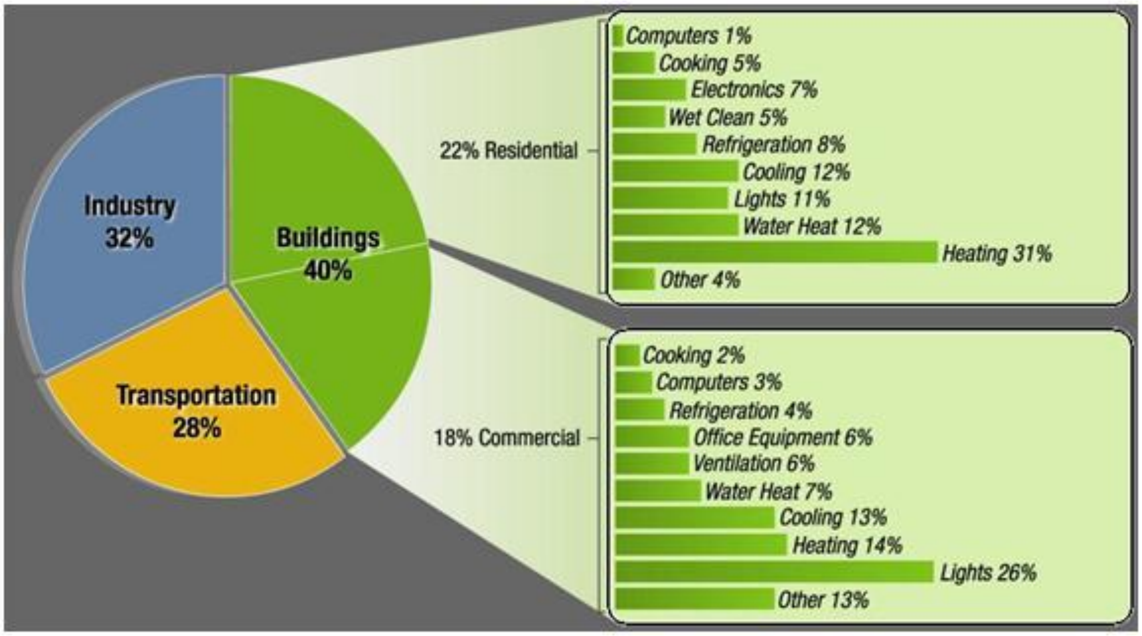

Figure 9. Energy use in a Building[15]

Office equipment only accounts for about 6% of the total energy use in commercial buildings, but there are also simple ways to cut energy use in this category. As I have mentioned above, the Energy Star program launched by the U.S. government helps the consumer locate energy efficient appliances by allowing those appliances to have an Energy Star benchmark on their products. Appliances, including copiers, computers, water heaters etc., are all available with Energy Star qualified models. The energy saving mechanism is simple. Energy Star copiers have sleep or power down mode when not in use. According to Energy Star, simply by these features, 30 to 40 percent of energy use can be trimmed down and may reduce

Figure 10. Plug Load Occupancy Sensor[18]

energy use in space cooling or ventilating. Another cost effective method is to provide a plug-load occupancy sensor to occupants. For example, if a computer always needs to be running, it can be plugged to the "always on" outlet. For scanners, printer, lamps etc. that are only used when the occupant is present, they can be plugged to the "energy safer" outlets, which automatically turn off the power if not used for 30 minutes (19).

2.5 Water

Besides fossil fuels, fresh water is another resource that is crucial to human life. Although about 70% of the Earth is surrounded by water, only 3% of that is fresh water and the rest is salt water. For that reason, using water wisely is very important for future generations and all the living things on earth.

The simplest way to conserve water, of course, is to use less water whenever possible. Since 1992, U.S. federal legislation requires toilet, faucet and showerheads to have at most 1.6 gallons per flush (gpf), 2.5 gallons per minute (gpm) and 2.5 gpm respectively (20). For the toilets, faucets or showerheads that were made before 1992, they do not have to meet the standard. This may be a good indicator that if fixtures are made earlier than 1992, upgrading them could make a vast reduction in water use.

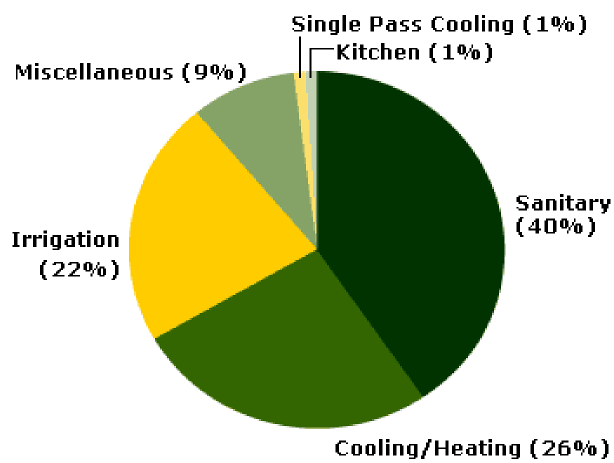

Figure 11. Water use in Office Building[22]

Adding aerators and occupancy sensors on lavatory faucets is another good idea. Aerators reduce the rate of water flowing through the faucets by mixing water with air while maintaining the pressure of the water. Thus, most people cannot tell a difference of an aerated faucet or non-aerated faucet. By adding aerators, it could reduce the flow rate of the faucet from 2.5 gallons per minute (gpm) to 0.5 gallons per minute. With the occupancy sensor, water use can be further reduced. Upgrading toilets and urinals can save water as well. Toilets with a dual flush system, which has a low flush rate of 0.8 gpf and a full flush rate of 1.6 gpf, are now available in the market. Assuming a person uses the toilet 3 times a day with one full flush and two low flush, a traditional 3.5 gpf toilet would have consumed 10.5 gallons per person per day in comparison of 3.2 gallons per person per day for a dual flush toilet. The amount of water saved would be substantial large when all the 3.5gpf toilets are replaced by dual flush toilets in a 100-story skyscraper. Moreover, waterless urinals are also available in the market. Waterless urinals use sealant liquid that has higher buoyancy than urine. Therefore, the sealant liquid will float on top of urine to prevent odor from releasing to the air. Even though the sealant liquid needs to be replaced periodically, supporters claim that waterless urinals save approximately 10,000 to 45,000 gallons annually (23). However, this amount of water saved is calculated by assuming the urinal is used 40 to 120 times per day. In addition, water use for irrigation can also be reduced if drip irrigation system or drought resistant plants are used in landscaping.

Other than upgrading fixtures, some owners could go beyond reducing water use by also recycling it. Rainwater can be captured for irrigation or even to flush toilets. This way, both water and energy use can be conserved, as treated water is not wasted on purposes that do not require clean water. Of course, capturing rainwater for irrigation is easy, but capturing rainwater or even grey water for toilet flushing is more complicated and costly.

Therefore, not many building owners would perform rainwater or grey water capture into toilet flushing system.

2.6 Building Automation System and Commissioning

The building automation system is used to manage all the operation systems including the HVAC system, lighting and the appliances etc. in the building, which can help cut down maintenance and utility cost. The system can maintain the temperature and air quality inside the building to the set range, provide lighting for the building base on set schedule, accurately monitor and record energy usage so that if unusual energy use or system failure occurs, engineers can locate the problem promptly (24). On the contrary, if a skyscraper does not have the automation system, when system failure occurs, it may take the engineering team days to find out the problem. In addition, the building automation system can be commanded via internet. Thus, immediate change for the system is possible when needed. According to George Denise, the General Manager of Cushman & Wakefield, "You can't manage what you can't measure (25)." Therefore, a good monitoring and control system is needed to properly manage the skyscrapers. In addition, building commissioning can also help to reduce energy use and make sure the HVAC, lighting, controls etc. in the building are working as designed. Research by Lawrence Berkeley Laboratory shows that the median cost of commissioning an existing building costs $0.30 per square feet with 16% annual energy saving and 1.1 years payback (43).

2.7 On Site Energy Generation

On the one hand, fossil fuel is a limited energy resource; on the other, humans are consuming energy faster and faster. Alternative ways to generate energy are definitely needed to sustain the current human-energy consumption speed.

For places that are mostly sunny throughout the year, installing solar photovoltaic would be an effective way of generating energy. Research has been done on the potential of energy generation through solar photovoltaic at different places by calculating solar insolation at different areas. Indeed, energy that can be generated each day is highly variable due to the difference in cloudiness, humidity and particles in the air each day. However, the average amount of solar intensity a particular place could get in a year does not fluctuate greatly. If an energy storage system is present to provide energy when the weather is not favorable for energy generation, solar photovoltaic (PV) can be counted as a very reliable energy source. Another drawback for installing solar photovoltaic is that even though its price is decreasing, it is still relatively expensive when compared to other energy sources (26).

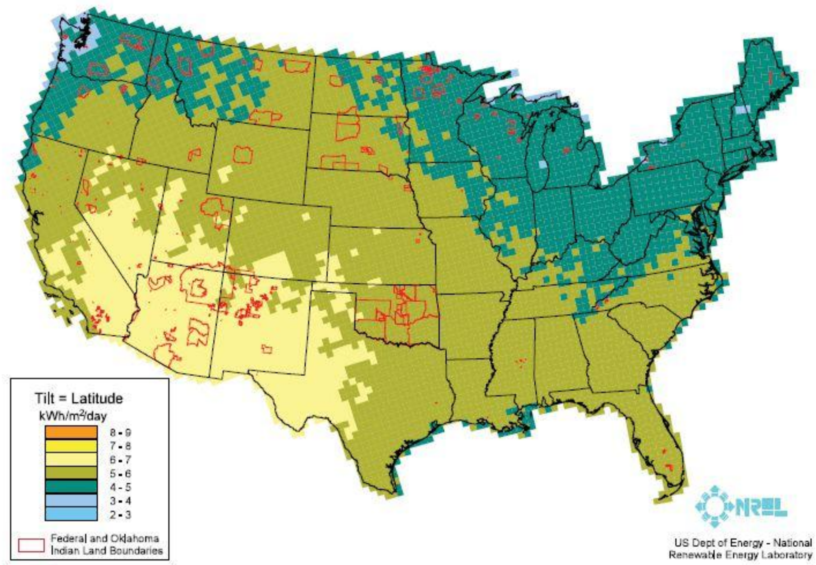

Figure 12. Solar PV Potential[26]

Another renewable energy generation method that makes use of solar energy is called solar thermal energy. It is cheaper than using solar PV, but due to the scale of this system needed to generate energy, it is not quite possible for a skyscraper owner to implant this type of energy onto their property.

Besides solar energy, other renewable energy resources are available but not commonly installed in building retrofits. Wind energy is available everywhere and is relatively cheap, but the space required for a wind turbine is relatively huge. It is not unfeasible to incorporate a couple of wind turbines on the roof of a skyscraper, and it may not be a very cost effective strategy. In the Willis tower renovation project, wind turbines will be installed to make use of the wind that the 110-story building sustains. While the project can receive an 80% reduction in energy use, the payback is 5 years, which is 6.7 times longer than the payback of the Adobe renovation project (28). Tidal energy and geothermal energy are cheaper than solar energy, but are only available in limited areas. Also, due to the cost and the amount of work needed to add these types of energy generating features on an existing building, it is not cost effective to carry out these renovations.

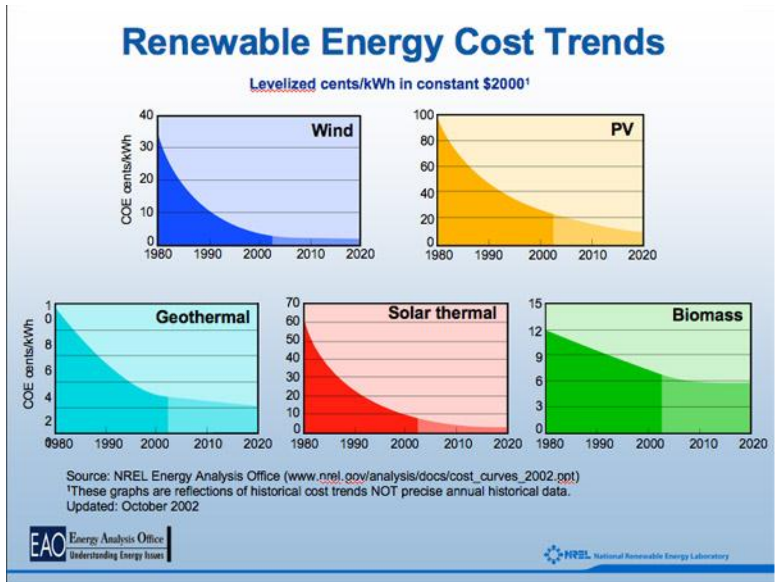

Figure 13. Renewable Energy Cost Trends[27]

2.8 Innovations

Everyday, scientists and researchers are working hard to find new ways to conserve energy and water while sustaining the luxurious lifestyle humans are now enjoying. Numerous new creative innovations, which seem to have great potential to be applied to building retrofits, are being introduced daily to the world.

Recently, 3M announced that they have found a way to keep building interiors cool during sunny days while generating energy. The 3M solar film, which is going to be available in the market in 2012, is a thin film that can be stuck onto windows and only costs half as much as solar PV panels. These thin films help reduce energy use for space cooling during summer, because it can absorb more than 90% of infrared light (29). The downside of this thin solar film is that it has only 3 to 8 percent of efficiency during peak intensity, which is about 20% of what the traditional solar PV can generate (29).

Another new innovation that has been proposed for use as an add-on to old existing skyscrapers is called the Eco-Skin. Though there are a couple of different concepts of Eco-Skin over the world, the basic idea is the same. Eco-Skin is a lightweight, transparent textile that can improve a building's insulation and generate electricity by wind or sunlight. Some propose to develop thin, lightweight, solar PV to use as the Eco-Skin. Others say they could use completely transparent polymer membranes, which weight 99% less than glass. An installed system would transfer mechanical energy from wind into electricity.

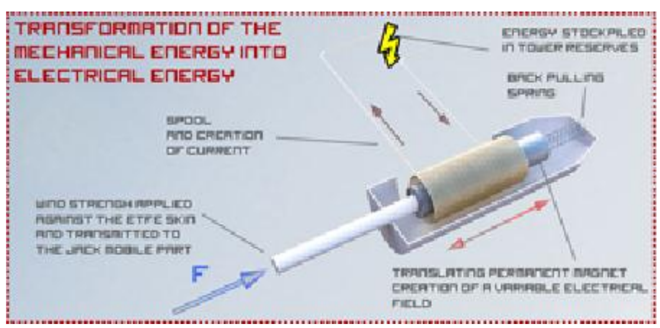

Figure 14. Mechanical System to transfer Wind energy into electricity[30]

3.1 Case Studies/Examples

3.1.1 Empire State Building

The Empire State has been an iconic skyscraper in the U.S. since it was built in the 1930s. Prior to 2008, this 2.7 million square feet, 102 story skyscraper used 88kBtu of energy per square feet, which generates 25,000 metric tons of carbon dioxide (31). Noticing the urgency for reducing the carbon footprint, the owners of the Empire State Building designed an energy retrofit. When the renovation project is completed in 2013, more than 38% of energy used and $4.4 million of utility cost per year will be reduced. It is also estimated that about 105 thousand metric tons of carbon dioxide emissions will be reduced over a 15 years period (32).

Similar to all building owners, the owners of the Empire State building are concerned for the economic aspects of the project. Thus, the retrofit team went through all possible retrofit choices and picked the eight most feasible methods for this project. Although the totally energy related retrofits cost is $106 million, the payback time is estimated to be only 2 to 3 years (33).

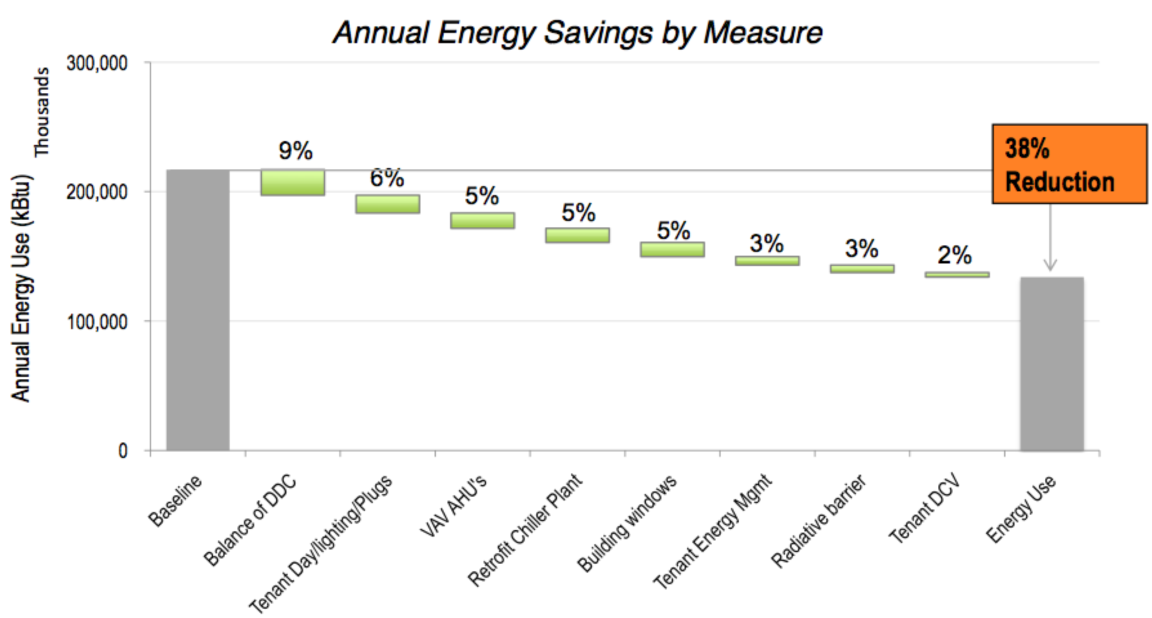

Figure 15. Annual Energy Saving of Implemented Projects [31]

Among the eight retrofits, three of them are dedicated to reducing energy load of the building. First of all, a coated film and insulating gas will be added between the two existing glazings of each of the more than 6500 double pane windows to reduce unwanted heat transfer. This retrofit is relatively cheap and is estimated that it could save 11M kBtu of energy per year (31). Besides the windows not being so well insulated, the radiators beneath each window give only half of the heat in the building, while the rest is lost through the wall. To reduce the energy load of the radiator, the project team has decided to add an insulated reflective barrier behind each radiator. By doing so, approximately 6.9M kBtu of energy and $190K of utility costs will be saved each year (31). The last method of reducing energy use is to enhance daylight and upgrade lights and plugs. In a typical office building, a huge amount of energy is used for lighting, even on a sunny day. Maximizing natural sunlight and upgrading lighting efficiency and control can help to reduce lighting energy load. Photo-sensors and dimmable ballasts will be installed so that when there is natural sunlight, artificial lighting can be turned on but dimmed to a desired level to reduce unnecessary energy load. Also, plug load occupancy sensors will be provided to occupants to plug in their appliances accordingly. These can further cut 13.7M Btu of energy per year (31).

After reducing the energy needs of the building to the lowest possible, two other retrofits will be used to maximize energy efficiency. With dramatically reduced energy load for space heating, a retrofit on the existing chiller plants will be good enough for delivering comfort for the occupants. The tubes, valves, motors etc. of the four chillers will be replaced while the shell of it will be kept. In addition, the controls, variable speed drives and primary loop bypasses of the chillers will be upgraded. To further enhance the energy efficiency, over 300 existing air-handling units will be replaced with newer units that have higher energy efficiency and better performance. Simply with these energy efficiency retrofits, another 22.8M Btu of energy per year will be reduced (31).

Lastly, energy-monitoring systems are being installed to control and track how energy is used in the building. The existing control systems will be upgraded and new direct digital control systems will be installed to optimize HVAC system performance by satisfying occupants' needs while reducing unnecessary energy load. About 20.6M Btu of energy will be saved annually by this retrofit (31). While the temperature in the building is perfectly adjusted, however, occupancy comfort is affected by both the temperature and ventilation rate in the tenant spaces. A demand control ventilation system will be installed to ensure adequate ventilation by measuring the carbon dioxide concentration in the tenant space. When ambient air is only drawn into the building when needed, about 4.6M Btu of energy used will be trimmed (31). Online energy data and benchmarking tools with information will also be provided to the building tenants. Tenants can therefore accurately check their energy use data and obtain sustainability tips to motivate themselves in achieving higher sustainability standards. This tenant energy management program is estimated to further cut the energy use of 6.9M Btu per year, making the totally energy reduction to be 38% (31).

With these energy retrofits, the Empire State Building becomes not just a landmark but also a model for the world. A model that tells the world that no matter how old and tall the building is, there are still feasible energy retrofits. The success story of the Empire State Building will unquestionably serve as a model for other building owners to follow by busting the green renovation financial rumors. and therefore, making green retrofits a even boarder trend.

3.1.2 Adobe System Headquarter Complex

The Adobe System Headquarter Complex is a complex with three towers located in San Jose, California. During California's energy crisis in 2001, big corporations were forced to cut down at least 10% of energy use (34). Adobe, of course, responded with energy reductions. After the owners of Adobe found that they were already good enough in achieving Energy Star recognition, they looked for another green building rating system – LEED. Since 2001, Adobe has spent $1.4 million on 64 energy retrofit projects, which were all completed in 2006 (25). Following the completion of retrofits, all three buildings in the complex received the Platinum certification, which is the highest recognition possible in the LEED rating system. The net cost of all projects was $1.11 million after $389,00 in rebates. Now Adobe saves $1.2 million per year and 35% per occupant in utilities and energy use respectively, with the average 9.5 months payback per project (25).

Since LEED counts not only how well the project building is performing but also how the building is affecting the environment, Adobe installed locked bike cages and provided incentives to encourage alternative transportation. Today, about 20% of the workers at Adobe are commuting by alternative transports, compared with an average of 4% in Silicon Valley (25). The project team is also concerned for the solid waste that is generated by the towers. Therefore, products with salvaged or recycled content, or locally harvested and processed, are given purchase priority. Additionally, Adobe enforces recycled programs, diverting 80% of the waste from landfill (25).

The project team of Adobe has implemented water conservation retrofits, which not only conserve water but also energy. Even though most of the landscape in the project area already used local plants to reduce maintenance needs, Adobe has installed a drip irrigation system to further reduce water use. Automated faucets, toilet flush valves and waterless urinals are also set up to trim water use. Lastly, Adobe has installed pump run web-based controls that are used to control pump-run time for the fountains. This shows other building owners that to conserve water and energy use, property decorations do not have to be removed but only need to be upgraded. More impressively, the cost of the pump-run time reduction upgrades was $3475 with an immediate payback by an annual energy saving of $5440 (25).

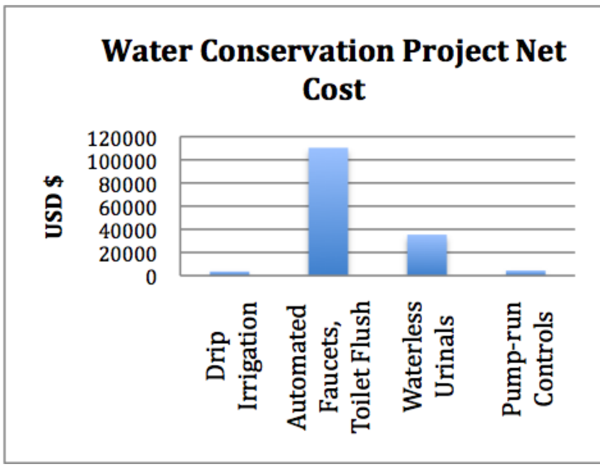

Figure 16. Net Cost in Adobe Water Conservation Projects[25]

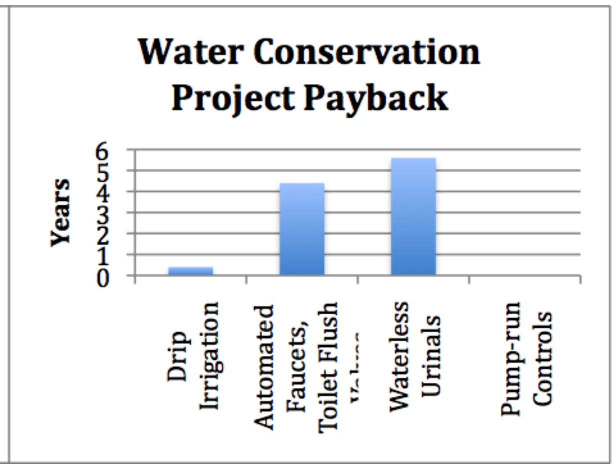

Figure 17. Adobe Water Conservation Project Payback[25]

Most cost-effective retrofits were chosen to reduce total energy demand by 39% with a short payback time. About 50% of energy usage can be reduced by modifying the cooling tower staging and sequencing, which costs only $575 but saves $12,000 in utilities annually(25). Motion sensors were also installed in conference rooms and offices in the towers at a net cost of $40,780 and an annual saving of $53,357. In addition to installing sensors, nineteen lighting projects were carried out to improve efficiency.

To maintain the towers to run efficiently, Adobe has installed a computerized maintenance management system. The system monitors and tracks energy and water usage; therefore, if there is a sudden sharp change in energy use, engineers can accurately locate the problem promptly.

Randall Knox III, the director of Global Facilities Services of the Adobe Systems once believed that 'green costs money; it doesn't save money (25).' However, once he saw the cost saving, he had to agree that going green does help financially and environmentally.

Although Adobe Towers are not as noticeable as the Empire State Building, their energy retrofits are even more outstanding than those of the Empire State, which can definitely help to serve as a reference to other building owners seeking green retrofits.

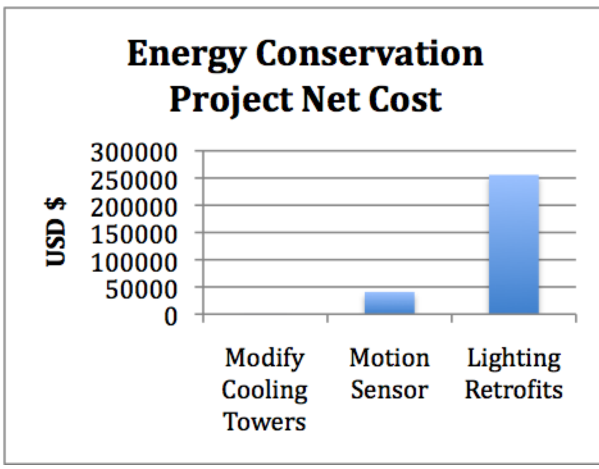

Figure 18. Net Cost of Adobe Energy Conservation Projects[25]

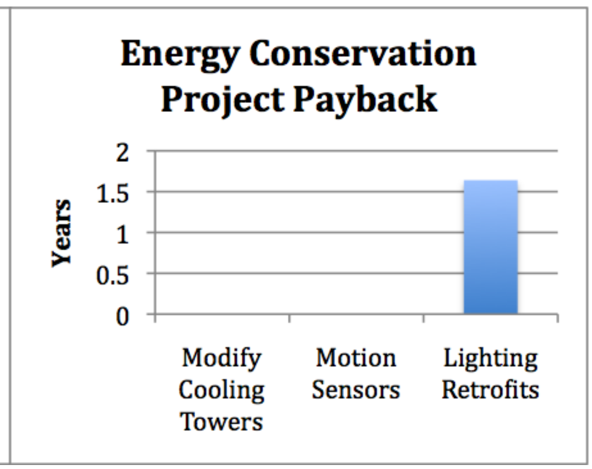

Figure 19. Adobe Project Energy Conservation Payback[25]

3.1.3 Willis Tower

The 110-story Willis Tower (formerly Sears Tower) in Chicago is the tallest building in the Americas and was once the tallest building in the world. In 2009, the building owners announced that they would carry out energy efficiency retrofits to reduce energy consumption by 68M kWh per year and by a cost of $350 million. The projects are anticipated to be complete by 2013 with 80% energy reduction and a 5-years payback time (35). The major energy savings for this renovation project include replacing all 16 thousands single pane windows and metal panels with more energy efficient ones to reduce half of the energy load in space heating or cooling. New gas boilers that can generate electricity, heating and cooling with 90% efficiency will be used. New high efficiency chillers will also be installed. The 104 high-speed elevators and 15 escalators in the tower will be upgraded to reduce 40% energy consumption (28). Advanced lighting control systems, which will automatically dim the lights and adjust to a suitable level of brightness if daylight is detected, will be installed to save 40% of lighting energy load (28).

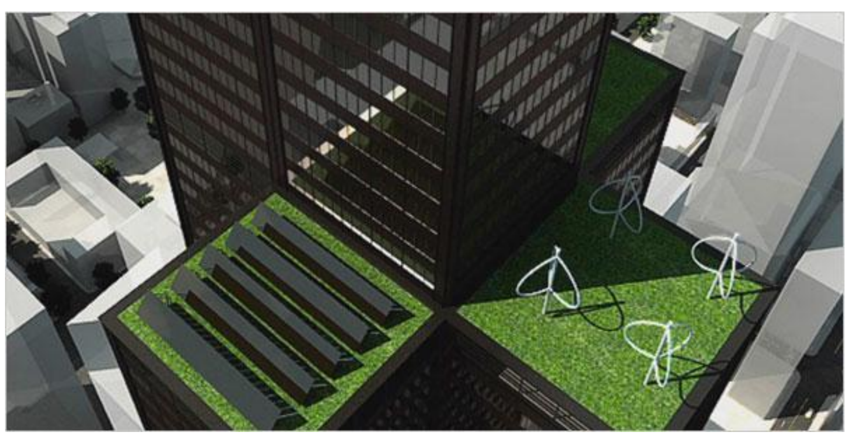

Figure 20. Roof Top of Willis Tower After Retrofits[36]

In terms of water saving, the Willis Tower will upgrade its plumbing system, restroom fixtures, condensation recovery system, as well as the irrigation system. Most details of the retrofits are not provided but retrofits that are rarely seen on an existing building including installation of green roof, wind and solar energy are going to be installed in the Willis tower.

Green roof and renewable energy are rarely chosen for retrofits in an existing building, because the cost is relatively higher than many other energy efficiency options. However, the Willis tower will install a solar hot water system to provide hot water to the building. As wind is usually stronger higher above the ground, wind turbines will also be installed to make use of the building's height to generate electricity for the building. A green roof will also be installed to reduce storm water runoff, the heat island effect and unwanted heat transfer.

The renovation project created 3.6 thousand jobs and helped reduced the water use by 10 million gallon per year and electricity use by 80%, equal to 64M kWh annually (28). Although most of the details of the project are not provided, Willis tower is another iconic building that inspires others to consider green retrofits. Most importantly, it shows the world that renewable energy generation and a green roof are still options for building retrofits despite their initial cost.

3.1.4 Paharpur Business Center

The 25 years old Parharpur Business Center (PBC) located in New Delhi, India is the first building in India to achieve LEED Platinum certification. The renovation project started when Kamal Meattle, the CEO of the Paharpur Business Center, was told that his lung capacity had dropped to 70% because of the air quality in Delhi (37). With a total of $471.5 thousands of investment and 6 years payback time, air in the PBC now has zero toxins and pollutants as compared with ambient air. Energy use has also been reduced by 54%, which can helps to reduce air pollution in Delhi.

The same as other energy efficiency renovation examples, lots of water and energy reduction retrofits were implemented to maximize the building's performance.

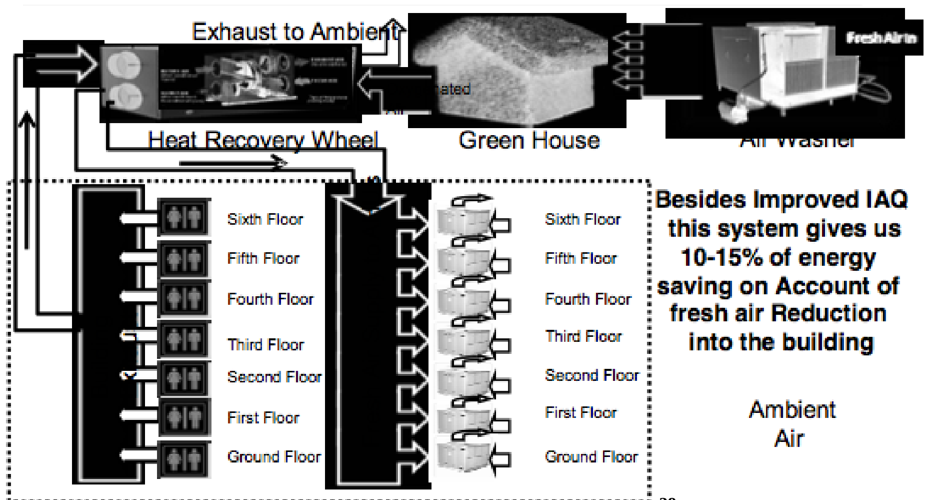

Figure 21. PCB Ventilation System[38]

Water reduction projects include water closet replacement projects and waterless urinal projects, which save 344.2 thousand gallons of water per year and 60 thousand gallons of water per year respectively (42). Sensor taps are also installed in all restrooms throughout the building. Soap free grey water harvested from kitchen and dishwashers is used to irrigate plants in the property. In additional, drip irrigation system and native plants are used in landscaping to reduce water usage. Energy reduction upgrades included lighting fixtures, cooling towers, air conditioner and HVAC system. The upgraded HVAC system reduced 20-25% of energy use while providing clean air inside the building by an innovative system (38).

The most innovative system in this project is the air purification system. Instead of using air filters to filter out the pollutants, plants are used to clean the air. First, air will be drawn into the building through the air washer. Then, it will pass through a green house where 1200 plants are placed. The air will be thoroughly cleaned by the plants during the day where they take up carbon dioxide and produce oxygen as a byproduct of photosynthesis. The cleaned air will then enter the building.

Though a 6-story building does not seem to be a high-rise building when compared to those in New York, Chicago or Hong Kong, the tallest building in Delhi only has 28 floors and was just built last year (39). While India is lack of building models for green retrofits, the success of PBC can show the rest of the growing countries that energy efficiency retrofits can boost the economy and health, too.

3.1.5 Glastonbury House

The Glastonbury House is a 23-story residential building in London, UK. $17 million dollars was spent to refurbish this building and receive 50% in energy saving and 40% in water reduction (40).

This residential building not only upgraded bathroom and lighting fixtures but also installed renewable energy systems and water recycling systems. Dual flush toilets and spray taps were installed to reduce waste of water. Lighting fixtures were upgraded to better utilize natural lights. Better heating system was also installed to enhance efficiency. Solar photovoltaic and wind turbines were installed to generate electricity to the building. Solar water heaters are used to provide hot water for the building (41). In addition to water and energy conservation, waste reduction is also a goal of this project. Therefore, eco-friendly materials were given priority to be used in the building project, and recycling is encouraged.

There are increasing numbers of model skyscrapers which successfully reduced energy and water use and hence, utility cost. However, there are not so many residential skyscrapers that have gone through this green refurbishment. Therefore, Glastonbury House will be a good model to demonstrate that green retrofits are not specify for office skyscrapers but also for residential buildings.

4 Conclusion

Although some basic energy reduction retrofits are seen repeatedly in the case studies of buildings from various places on earth, there is no perfect formula for building retrofits due to geographical and building purposes differences. For example, in San Diego, Hong Kong, Bangkok or Havana, building owners may want to invest in upgrading the cooling towers instead of the heaters, which may not even be used once a year. For that reason, USGBC has recently added regional priority credits to projects that are outside of U.S., Puerto Rico, the U.S. Virgin Islands, and Guam in the LEED 2009. With LEED being even more universally favored, more buildings all over the world are anticipated to carry out green renovations for LEED, because more local building models will be available for references. In addition, a recent research on commercial buildings in the U.S. and Europe has shown that rents for buildings that have gone through green renovations are substantially greater than conventional buildings (21). George Denise foresees that in the future, green building will no longer be the exception but a norm, which would further pushes all buildings to go green (34).

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