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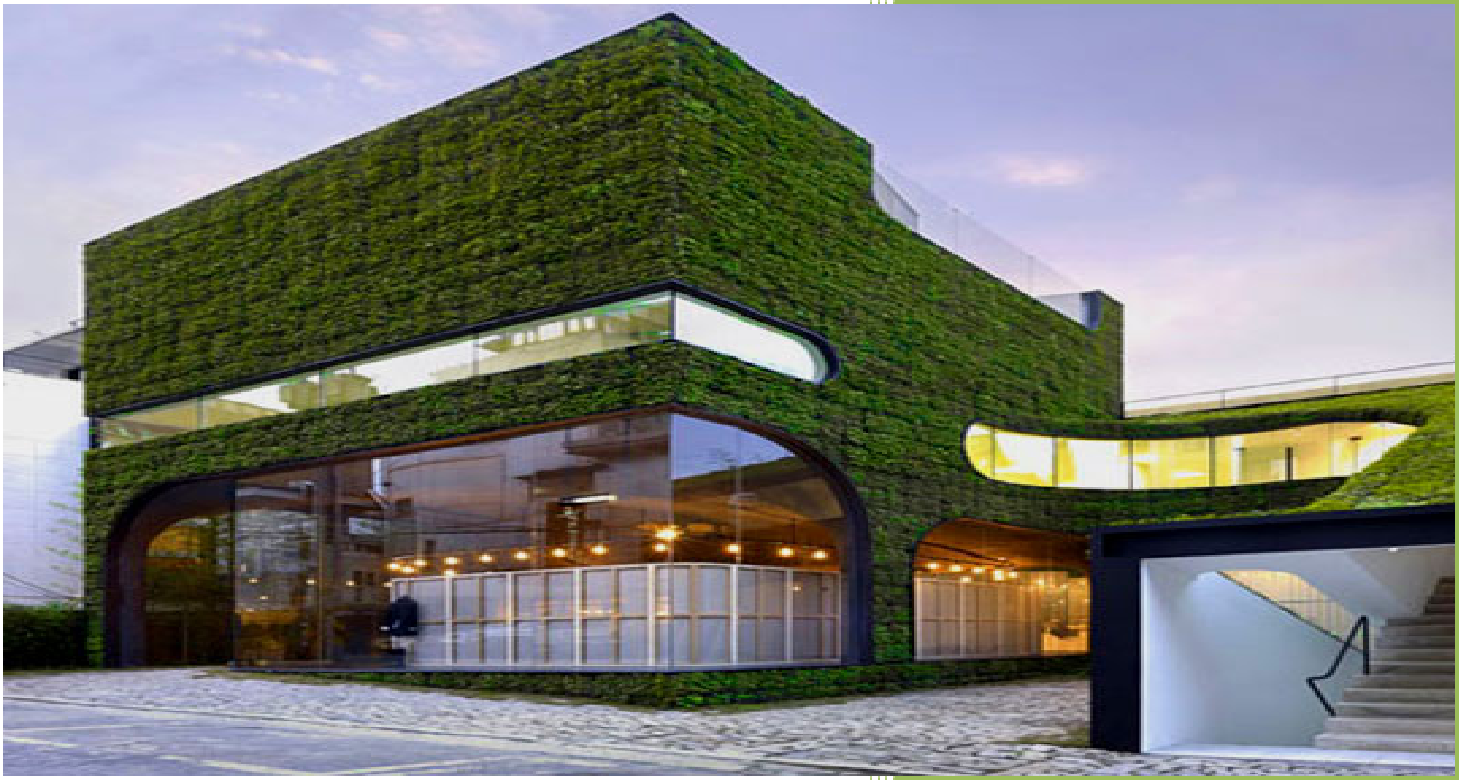
Fall Term

Green Construction: Innovation in Material & Design



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Abstract /Summary

Green construction is the creation of an environmentally friendly building that uses less energy, water and construction products, which in turn leads to less maintenance and minimal infrastructure. Green buildings also improve indoor air quality, enhance the buildings marketability and could lead to an increase in the occupants' productivity. Construction uses more than 30% of the total energy and more than 60% of the electricity used in the U.S. annually [1]. Reducing these demands will have a positive effect on the world that we live in. Green buildings consume less energy relative to buildings that are not up to these standards. Green construction uses less energy and natural resources at the onset and in the long run as well.

Americans spend up to an average of 90% of their time indoors and so this environment plays a large role in their lives [1]. By making a building easier to live and work in will have a large affect on their quality of life and also their production.

There were five different fields that we looked into more closely to see how different technologies affected green construction. The fields that were looked into are the following: architecture, biomimicry, mechanical, chemical, and computer software. Architecture is how and what methods should be used to make a building green. Biomimicry is how nature can be used to mimic designs in green construction. Mechanical is how thermal and air quality designs can be used in green construction. Chemical is how the different chemicals used by the industry for their final products and how these affect the end users. Computer software is how computer technologies can be used to model and simulate building systems before construction begins as well as during their operation.

OHSU's center for health and healing was looked at as a case study to see how these different technologies were used on an actual project. The reason why this building was looked at was because of its high LEED rating. With such a high LEED rating (platinum), there was a lot of innovative idea that had to be used to make it a green. Some of these innovations included the following: water harvesting system to recycle all of the water that has been collected and use this gray water for janitorial purposes, flushing toilets, ect.; using natural ventilation in the stairwells; eliminating HVAC in as many areas as possible by using chilled beams and other integrated energy storage systems, using photo sensors on the shades to create electricity.

The end goal of green construction is to have all new buildings become self sustainable by the year 2030; this is called the net-zero goal. This means that these buildings will create their own energy and collect enough rain water for their building functions. A problem with this goal is that 85% of the buildings that we will be using in the year 2030 are already built and will not meet this goal. So it is important to prove to the owners of these buildings that there are other implications from building a green building such as improved performances from their work force. This proof will provide an incentive for these buildings' owners to have them retrofitted in order to meet the net-zero goals.

These is still a long way to go before a buildings can be made self sustainable and the only way that this goal can be made is if we change our policies. President Kennedy once said that we would put a man on the moon in the next ten years. Everybody at this time thought that this goal could never be reached, but through hard work and dedication this goal was reached. So in order to reach this goal of net-zero by 2030, we must put in this hard work and dedication.

Introduction to Green Building

Green sustainable architecture means creating buildings that use less energy, water and construction products, which leads to less maintenance and infrastructure. Also, the idea of green architecture is to include natural characteristics and resources on the site, and to use recycled materials in order to reduce building costs. So, the goal is to reduce the amount of wasted energy and materials in building, as well as what resources the occupants will use. As a result, green sustainable buildings provide a secure, accessible, healthy and productive indoor environment to their occupants. Moreover, there is a significant connection between the indoor and outdoor environments, that of the "building envelope." This envelope includes "the outer elements of a building, foundations, walls, roof, windows, doors and floors." [1]

Technologies lead to Innovations

The green building industry has been getting an increasing amount of attention in recent years. As governments and citizens become more concerned about the issue of global warming, more attention is being paid to buildings, which are one of the largest greenhouse gas contributors. The result is a growing movement within the building design and construction industries towards sustainable buildings. But the question of what is sustainable building design is one that is still being researched. Therefore, there is a close tie between research efforts in the academic sciences and actual design practices in the building industry. The areas that will be explored in this discussion are architecture, biology, mechanical engineering, chemistry and computer science. These topics, and their sub focuses, were chosen not because they are the only fields with research relating to green building design but because they offer insight into the extensive range of sustainable technology development. As the need for sustainable technologies and designs becomes ever more important, science is trying to offer the research foundations for technology development that will help contribute to the effort.

Architecture

In green building, architects actually changed their way of dealing with designs by moving from the conventional approach to a new one that includes all parties that could be involved in the project from the beginning. This approach starts form the first stage of the design through the development of construction documents, and finally the construction stage. There are six basic principles for designing green sustainable buildings that architects have to focus on, as follows:

1- **Site selection:** the first step in creating sustainable green buildings is based on choosing the proper location, orientation and landscaping [1]. One significant component of this is passive solar design, which means the use of the "sun's energy for the heating and cooling of the building." This can be achieved by orienting the building relative to the sun's position, so that there will be optimum daylight within the building's spaces. The same idea can be applied to the windows' sizes and positions in relation to the sun's position. In addition, considering climate conditions such as temperature, moisture, wind, etc., is very crucial, since these can impact the construction materials and the energy performance of the building. [2]

2- **Reducing energy consumption:** sustainable green design should "meet or exceed applicable energy performance standards." Also, it has to consider climate conditions, to optimize thermal insulation performance for both heating and cooling seasons, to reduce the amount of heat by using light colored finish materials or vegetative components on the roof. Selection of glazing, and determining its orientation, size, and performance in relation to indoor and outdoor climate also has to be considered in reducing energy consumption. In addition, the design should call for applying effective solar exterior shading devices such as overhangs and vertical fins, integrating photovoltaic panels as a method of generating on-site renewable energy, and analyzing the building's envelop performance by using "energy simulation and life cycle analysis tools" [1].

3- **Water conservation:** seeks the efficient use of water by reducing, managing, and treating site runoff, as well as recycling water for on-site use. This can be done by using a roof vegetation to capture, filter and reuse the rain water on site. The captured water can be recycled and used for irrigation, toilet flushing, or other areas that can use gray water [1].

4- **Using environmentally friendly products:** building designers should "evaluate environmental performance of the building envelope components or products" by using life cycle assessment tools like ATHENA and BEES. Also, use of efficient materials that can be recycled and are composed of renewable resources will reduce life-cycle environmental effects such as global warming, resource consumption, and human toxicity. The main criteria for selection of green materials that should consider are the following: 1) resource efficiency, 2) indoor air quality, 3) energy efficiency, 4) water conservation and 5) affordability [3]. The benefits that can be gained by using green materials are as listed:

   A) Minimized maintenance and replacement costs over the building's life.

   B) Energy conservation.

   C) Improved residents' health and productivity.

   D) Lower costs with respect to modifying space configurations.

   E) Effective design flexibility. [3]

5- **Enhancement of indoor environmental quality:** it is desirable to increase day lighting by designing windows in a way that allow residents views outside, and that do not negatively impact their visual comfort; thus to design glazing systems in a way that maximize the use of daylight. So, in order to maintain a consistent light level, electrical lighting should be controlled to correspond to daylight levels; internal shades or blinds should be used to avoid glare reflection. Sufficient ventilation and moisture control will inhibit the use of materials that contain highly volatile organic compounds (VOCs) in such products as paints and coatings, and sealants and adhesives [1].

6- **Optimize operational and maintenance practices:** it is necessary in the design stage to call for materials and systems that decrease maintenance requirements, water and energy uses, and toxic chemicals and cleaners; such materials are “cost effective and reduce life-cycle costs.” In addition, residents and operators should be trained comprehensively on preventive maintenance programs to maintain all building systems linked with the “building envelope functioning as designed.” [1]

Biomimicry

Humans have been looking to nature for inspiration and guidance since the beginning of civilization. But it has only been in recent years that this practice has been given a specific name- biomimicry. The basic premise of biomimicry is that nature has had 3.8 billion years worth of research time in a vast laboratory with extensive testing to develop its winning designs. Therefore instead of trying to reinvent nature’s designs, our development efforts would be better spent trying to understand the why and how of nature’s designs so that we can learn from them and perhaps even use those concepts in our own designs. In the case of building design, there are two main areas where nature can offer guidance- building design and building technologies.

Building Design

The idea of green design is one that is getting a lot of attention in the building world. Biomimicry is playing a part in the development of greener, more sustainable designs in the building environment. Building shape and ventilation are two of the most notable areas that have been influenced by biomimicry.

The discussion of building shape is an interesting one. A broad sample of traditional structures from around the world would produce a population different from what we see in modern cities. Many traditional home structures were more likely to be round than square or rectangle. Yet the modern building are most often some variation of a rectangle. Nature recommends the round structure instead. The nautilus shell is round and spirals up through its length. This design provides a shape that increases the strength and stability of the structure, while also decreasing the amount of materials needed to build it. [4] It is also a more aerodynamic shape, which is helpful for tall structures. One of the reasons for the nautilus shell inspired curved design of the Chicago Spire is this reduction of wind forces on the building. [5,6]

Nature also offers guidance on more efficient ways to design the ventilation systems for buildings. A great example of this is the mimicry of termite amounts in naturally ventilated buildings. Termites have learned how to survive in climates that experience extreme swings in temperature by developing building methods that tightly control the indoor temperature of their mounds. Since HVAC systems consume around 40% of the building’s total energy use, developing successful methods for natural ventilation systems (i.e. ventilation that uses the building’s design, not a powered HVAC system) has significant potential for creating more sustainable buildings. [7]

Different termite species use different methods for controlling the indoor environment of their mounds. On the Ivory Coast, the termite mounds have a multi-duct air exchange system within the mound. Hot air rises through one of two main ducts running vertically through the mound. It is then exchanged at the top through a series of smaller ducts with cooler fresh air from outside. The cool air then sinks through the mound via the second main duct. This process helps to both control temperature and moisture levels within the mound. In Uganda, the mounds also have a vent at the top for hot air to escape. But in this case, the cool enters from the bottom of the mound instead of the top.[7] An excellent example of a termite inspired building design is the Eastgate Building in Harare, Zimbabwe. The natural ventilation design was modeled off of one of the termite mound systems. It has proven to be a successful design for human buildings, as well as termite ones. The Eastgate Building uses only 10% of the energy of a comparable building with conventional HVAC design.

Both methods are successful and emphasis the idea that solutions in nature are not universal. A design that works in one area may not work in a different area if the climate and geography are different. This is an important lesson for building designers. The best design reflects the environment in which the building will reside.

Building Technologies

The other area where nature has some advice to offer the building industry is in the development of technologies. One technology that is currently being included in many building design is solar panels.

With the popularity of solar panels increasing, there has also been an increase on research around how to improve their design, efficiency and manufacturing. One of the most popular biomimicry areas of research is photosynthesis. Plants have developed a very efficient system from converting solar energy into storage sugar energy. The efficiency of photosynthesis is 95-99%, whereas solar panels are only in the 13-18% range. [8] But nature does not give up her secrets easily, so researchers still have a long ways to go before photosynthesis can be replicated on a large scale.

Other areas of biomimicry research are looking at moth eyes and cicada wings for design ideas and sea sponges for better manufacturing techniques. The idea with moth eye research is that moth's have developed a survival trail of eyes that do not reflect light. Reflected light would make their eyes, and therefore them, show up at night. The anti-reflective coating helps them remain hidden from predators. The advantage for solar panels is that application of an anti-reflective coating would allow them to capture more of the light that hits the surface and therefore become more efficient. Peng Jiang, an assistance professor at University of Florida, is researching this as a possible application of the anti-reflective surface of moth eyes. [9]

The research around cicada wings is also looking at replicating a coating that occurs in nature. Cicada wings are able to easily repel water so water on their surface essentially becomes a cleaning agent by washing away anything stuck on the surface. Since solar panels are actually multiple smaller panels connected together in series, cleanliness of the panel is an issue of major concern. Dirt or dust covering one section of the panel can cause a loss of power generation for the entire panel. Therefore the water repelling coating inspired by cicada wings could also help improve solar panel efficiency by making them more self cleaning during rain showers. [9]

One area of concern for many sustainability engineers is the fact that the manufacturing process for the silicon wafers in solar panels is anything but green. It's an energy intensive process and uses large amounts of noxious chemicals. A more green manufacturing process would in turn make the panels themselves more sustainable in their cradle to grave cycle. Researchers at University of California Santa Barbara are using sea sponges as guidance for a more sustainable silicon wafer manufacturing process. Sea sponges are able to create silicon based skeletons using nothing but seawater and proteins processed at ambient temperature and pressure. The researchers are learning to replicate the sea sponge technique into thin film photovoltaics. [10]

Mechanical

There are many designs that can be used from the mechanical trade that can be used in "Green Construction." This wide range of designs can come from areas like heat and mass transfer to the actual mechanical systems like HVAC.

An example could be a computational fluid dynamics model that looks at the wind pressure on a buildings surfaces to access if natural ventilation could have potential for ventilating the building [11]. Other ways to ventilating a building would come from mechanical ventilation using HVAC or to have mixed-mode ventilation that utilizes both mechanical and natural ventilation techniques [12].

Indoor Air Quality (IAQ) is another big issue for "Green Construction." It is important to enhance the IAQ within a building; this contributes to the well-being and comfort of the occupants. Many of the air pollutants that an individual inhales are from indoor air. These indoor air pollutants can cause health related reactions or allergies. It has been estimated that 17 million Americans suffer from asthma and another 40 million have allergies; thus low IAQ can contribute to millions of days of occupants being absent from work or school [12].

Thermal comfort is also a big issue for "Green Construction." Making sure that there is the right level of thermal comfort that can be controlled by an individual occupant or in multi-occupant spaces (e.g., classrooms or conference areas); this contributes to increased productivity, comfort and to the well-being of the occupants of the building. For multi-occupant spaces control systems are set up so that when the area is not being used, unnecessary thermal energy is not wasted in these areas. When they are in use, thermal energy is then brought into these areas to bring the comfort level back to normal standards [12]. Many mechanical HVAC systems are deliberately designed and built oversized to assure thermal comfort at all times. So making the HVAC system the "right size", is a mechanical challenge for all "Green Construction." [11]

With all of these areas within the mechanical trade to look at, only two were analyzed in detail. The two areas focused on are heat islands and green roofs and will be explained in the following subsections.

Heat Islands

A heat island is an urban area having a higher average temperature than its rural surroundings owing to the greater absorption, retention, and generation of heat by its buildings, pavements, and human activities [13].

When people start to get hot, they turn up the air conditioning. As the use of air conditioning goes up the power consumption goes up with it. As power consumption goes up, thus more power has to be generated to support this excess consumption of power. Power is generated mostly by fossil fuels and because of heat islands more of these are being consumed to keep the temperatures at a reasonable level of comfort [14]. "The motivation for really caring about the urban heat island is typically driven by summer time conditions. It is also not just extreme climates; in many cities across the U.S. you have millions of people living in the city who experience extreme heat conditions in the summer. The urban heat island will increase their air conditioning consumption, it will increase their risk for heat related mortality and mobility, and it will increase air pollution.” Figure1 shows what an urban heat island look like and the heat bubble it produces around a city:

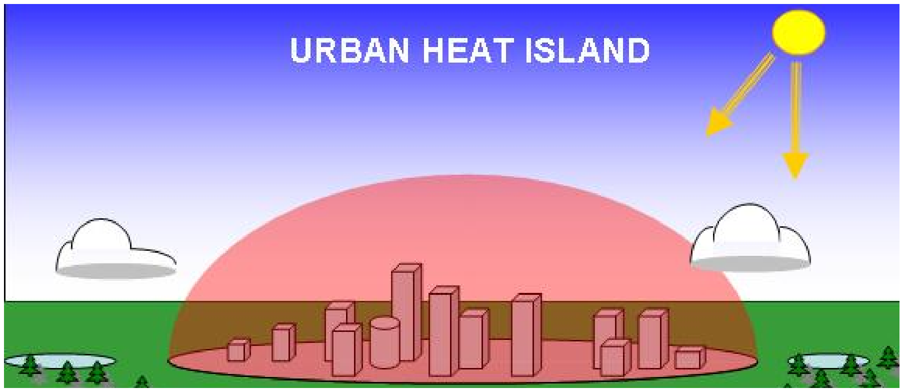

Figure 1: Urban Heat Island Affect [15]

If the daily maximum temperature is above 15-20 ^{o}C, researchers [16] have found that the peak energy consumption in these five U.S. urban cities (Los Angeles, CA; Washington, DC; Phoenix, AZ; Tucson, AZ; and Colorado Springs, CO) rises by 2-4% for every rise of 1 ^{o}C. This additional increase in temperature from the heat island results in more air conditioning being used. Because of this extra air conditioning cost, it is responsible for 5-10% of the urban peak energy consumption [17].

Increasing the albedo on urban surfaces and planting trees in urban areas can limit or reverse the urban heat island effectively and inexpensively. Were albedo is defined as “the fraction of incident electromagnetic radiation reflected by a surface.” [18] Cooler surfaces are more effective and cost efficient when compared to planting trees. “In many hot environments it makes a lot of since. You can put a white membrane on a roof that does not cost you any more money compared to a black one.” The results from changing a surface to a lighter color is immediate; while planting trees could take up to ten or more years before the tree is large enough to produce significant reduction in energy consumption. Figure 2 shows differences between materials and there solar reflectivity levels and how this affects the temperature of the surface when they have been facing the sun [17].

Researchers have shown that there is a 20-40% savings (from energy and cost or additional air conditioning equipment) on a single building by increasing the albedo. Computer simulations have shown that these numbers could nearly be double by the indirect effect of wide scale increased albedo level adopted by a city. At this maximum potential, shade trees and cool surfaces could save up to $10 billion annually in energy and air conditioning equipment cost nationwide for the U.S. This correlates to eliminating 27 million tons of CO_2 emissions [17]. Any time you increase your albedo, it is “going to hurt you on your heating bill and it will always save you on your air conditioning bill.”

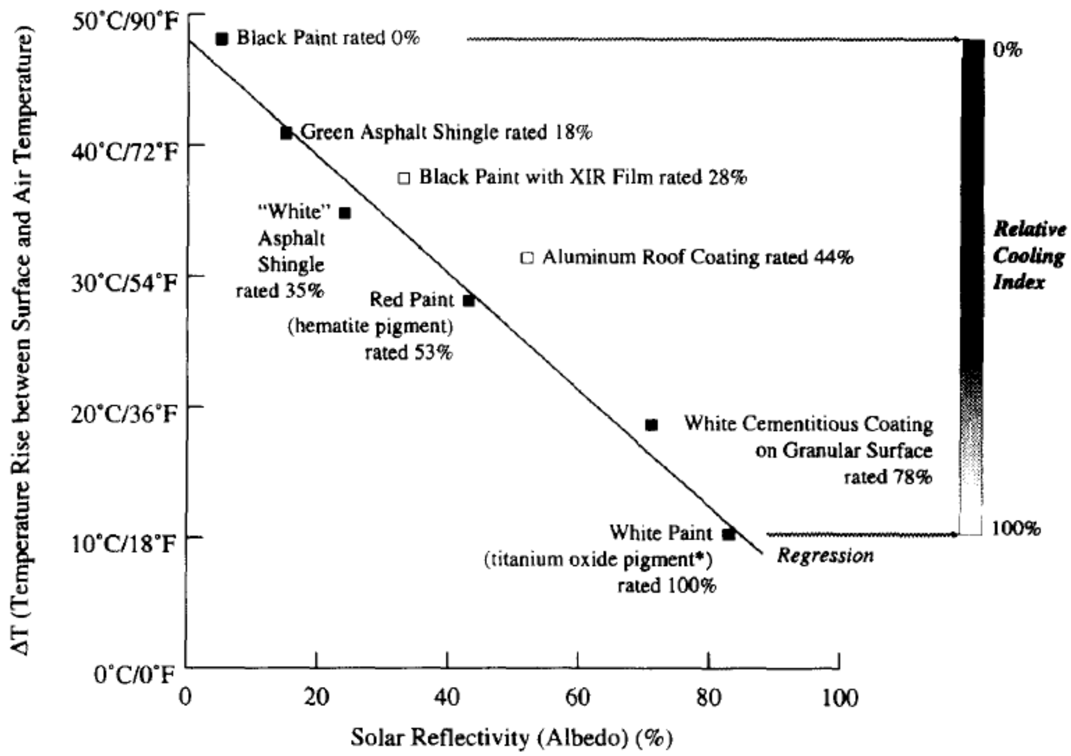

Figure 2: The difference between surface and air temperatures vs. solar reflectivity of roofing materials and paints facing the sun [17]

There is a movement to incorporate this technology into the residential market. A problem with implementing this in residential areas "is that houses that have a sloped roof, and people do not want to have a high albedo on it. So the residential sector has not been implementing high albedo roofs vary widely." But there are new technologies for new types of coatings that have been developed, "where the pigment in the coating uses something other than carbon black as a pigment. Chemically you can create a coating that might be gray or light brown, a more common type of roof top color, that to the naked eye, the visible spectrum does not have much reflectivity, so there is not a glare concern. But in terms of integration over the solar spectrum, it is reflecting a lot of the energy outside of the visible spectrum." As the manufactures bring the cost of these down for these types of products, you will see a larger percentage of residents applying these products onto their own homes.

Green Roofs

A green roof is a vegetative roof system that is used in place of a conventional roof [19]. There are many benefits that Green Roofs provide and are aesthetic appeal, energy savings (the soil is an extra insulation layer and the vegetation provides shade for the soil which lowers its albedo level), habitat, and water reduction [20].

Green roofs are composed of several layers and can be seen figure 3.

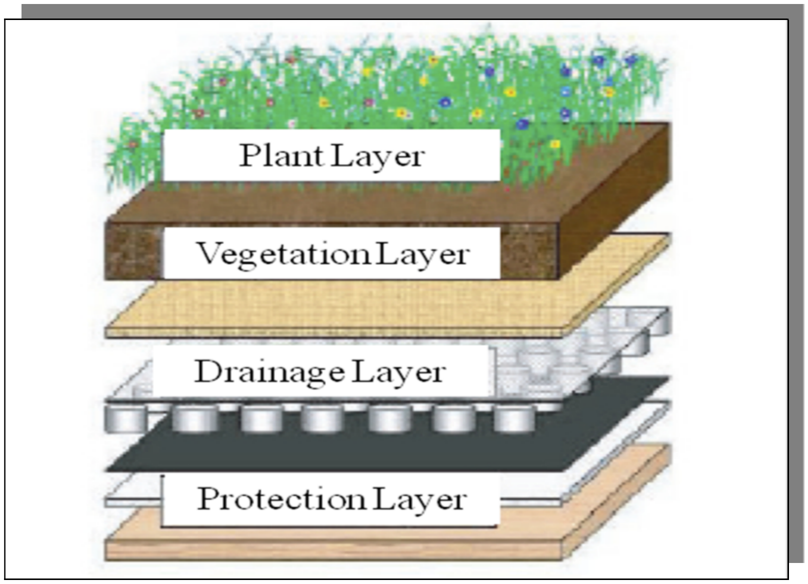

Figure 3: Green roof diagram showing layers of the green roof [21]

A green roof is a roof that contains a growing media (soil) layer and its outer most layer is covered in vegetation. Under the growing media, there is a drainage mat that is designed to retain water, act as a root battier, and prevent the soil from being carried away. A water proof membrane is put between the roof surface and the drainage mat. This layer prevents roof leaks, especially if additional water is added to the roof for irrigation for the plants [20].

Some factors that affect the efficiency of a green roof are how thick the soil layer is, type of vegetation used, and how much area the vegetation covers. Soil thickness can be as thin as 5-10cm or as thick as 1m. These different of ranges are used depending on what type of vegetation is used. Changing the soil thickness results in changing the thermal conductivity of the soil. A thicker soil layer increases the insulation, thus reducing the demand for both heating and cool, but there is a larger savings in colder climates. The vegetation itself also has a large affect on a green roof. The most important of these affects from a standpoint of heat transfer through the roof are its height, Leaf Area Index (LAI), fractional coverage, albedo, and stomatal resistance. Increasing the vegetation density (fractional coverage and LAI), reduced the summer electricity usage. But by increasing these variables, it also increased the winter heating energy use due to the shading effects that were so beneficial in the summer, but are costly in the winter [20].

In the U.S. green roofs have not been around for very long, while there has been a lot of work throughout Europe over the past few decades - even centuries - on green roofs. “Green roofs have been around for centuries latterly, as a mechanism for insulating the structure from the outside environment.” There is growing interest in green roofs impart because of the “variety of benefits that they can provide. The benefits range from urban storm water mitigation to urban heat island aspects for energy consumption. Building contractors and owners are willing to take more risk now that there are more examples of successful buildings. They are more comfortable putting this on their building.”

From a research point of view, green roofs “are still relatively new… research is still recent. More and more there are people who are trying to quantify what are the benefits to the building in terms of energy consumption, what are the benefits for storm water reduction, storm water quality (what coming down the down spout). This is also a reason why you do not see green roofs as much because there are a lot of unknowns. So the research is now starting to answer these questions."

From a residential stand point, green roofs are a city-approved storm water management technique and qualify owners for city incentives (or at least in Portland it is). Starting in 2006 in Portland, O.R., homeowners and building owners are eligible for a maximum 35% discount on their municipal storm water fee for qualifying green roofs [19].

Chemical

The idea of harvesting rainwater is not new to people; in fact, it is an old idea that has gained more attention and publicity recently. As we move on to the next decade, our future depends on turning innovate ideas into reality. Converting rainwater into usable or drinkable water is one of these ideas that will result in assurance of water supply for the growing population. To illustrate this, if you have a roof area of about 2,400 square feet in Central Texas where the yearly average rain is 31 inches, a possible of 44,000 gallons of rainwater can be collected. To achieve sustainability in water resources, harvesting rainwater is a potential solution.

Looking at the process of harvesting rainwater, we would realize the simplicity of it. When rainwater drops it gets collected mostly from the roofs of building. Then, gravity plays its role by flowing the water into gutters and pipes into the storage tank. Once we reach this point, the water could be used as is in landscape or flushing toilets. Otherwise, the water could be filtered with chemicals to achieve the high quality drinking water level.

There are some challenges when it comes to keeping rainwater clean; some of which are twigs, dust, bird dropping, and leaves. In order to prevent these dirty elements from ruining the water, a method called "first flush" is used. This method consists of sacrificing the first flush of water for the sake of keeping the rest of water cleaner. Furthermore, each of the pipes or downspouts have access to a plugged pipe that has a few cleanout plugs at the bottom. When the plug is shut, the rainwater would fill the downspout until it reaches the top. After that, the water is directed to another pipe that is then connected to the storage tanks. Obviously, each of these "first flush" pipes have to be cleaned after each rain session in order to be ready and empty for the next rain event. In an event where the storage tank is full, each of the "first flush" pipes can be connected to additional tanks after they are cleaned from debris. [22]

There are a number of water-treatment technologies that can convert rainwater into a high-quality drinking water. However, the most commonly used technologies to treat rainwater are filtration and disinfectant technologies. A combination of these technologies is recommended in order to achieve maximum purification of water. It is also important to mention that the treatment stage is done after the rainwater has been collected at the storage tanks. The actual treatment is done at different tanks than the main storage tank to ensure that the water does not get re-contaminated. Filtration technologies have a number of different systems that have a different level of microbial pathogens treatment. Below a table shows the different effectiveness of filtration treatment.

Filtration System	Types of Pathogens Removed
Bag Filters	Parasites (Cryptosporidium, Giardia, Toxoplasma)
Cartridge Filters	Parasites
Microfiltration Membranes	Parasites, most bacteria
Ultrafiltration Membranes	Parasites, bacteria, most viruses
Nanfiltration Membranes	Parasites, bacteria, viruses

As shown in the table above, some systems do not have the capability to remove all types of pathogens. This indicates that other disinfectant systems are strongly recommended in order to guarantee complete microbes removal. In addition, the more sophisticated the filtration system is, the higher the cost to purchase, operate, and maintenance the system. Another important thing is that the membrane systems must be flushed and backwashed periodically to remove all particles that are traped on the surface.

The next important technologies used besides filtration technologies are disinfection technologies. These technologies consist of ultraviolet light and chlorine. Ultraviolet light or (UV) is extremely effective against cryptosporidium. Chlorine, on the other hand, is ineffective against cryptosporidium but is extremely effective against viruses. In addition to this, UV is more effective against parasites than viruses while chlorine is more effective against viruses than parasites. Ultraviolet light takes a tenth of a second to inactivate pathogens while chlorine takes about several minutes. Another important difference is that UV can only work in relatively clear water while chlorine can be used in both clear and unclear water. [23]

Computer Software

Software is more commonly known as Computer Aided Design/Drafting (CAD) and has been used in the construction industry for at least the last 20 years. The aim of these software tools is to provide an effective means of informed design decision making [24]. In the case of green construction, this objective still holds true but an additional focus is on the simulation of building systems that will have minimal negative impacts on the environment.

For the purposes of this paper, building simulation tools can be categorized in terms of the systems they simulate and evaluate. The focus tends to be on:

i. Energy and Atmosphere
ii. Life Cycle Assessment (LCA)

Energy and Atmosphere

Energy and atmosphere includes HVAC & R (Heating, Ventilation, Air-Conditioning & Refrigeration) and lighting systems. Since HVAC & R systems are such high energy consumers, most building simulation tools aimed at saving energy will simulate HVAC & R systems. Examples include *DIALux*, *CONTAM*, *Adeline* and *Apache*. The table below shows a brief description of these building simulation tools along with their inputs and outputs.

Software	Description	Input	Output
Adeline	Integrated environment for analyzing daylighting, electric lighting and passing results on to whole building analysis.	Geometry & surface characteristic codes inputted using 3-D CAD	Graphic displays of interior illuminance levels, including 3-D renderings; lighting design & calculation results
CONTAM	Multi-zone airflow and contaminant transport analysis program. GUI: centered on a SketchPad that provides input of building topology. Simulation engine: calculates zone pressures, air flow rates and contaminant concentrations.	Interior or exterior scene, graphical representation of building as series of walls that make up the zones	On-screen displays of pressure drops and flows superimposed on the graphic building description
DIALux	Light planning program for calculation and visualization of indoor and outdoor lighting systems.	Room or exterior scene created in DIALux or imported as DWG or DXF files	Lighting design and calculation results saved as pictures, movies, electronic printouts and/or printed on paper.
Apache	Design mode: covers calculation of heating, cooling and latent room loads, the sizing of room units, internal comfort analysis. Simulation mode: performs dynamic thermal simulation using hourly weather data.	Geometric building imported from a range of CAD systems via customized links or DXF files.	Wide range of outputs in tabular and graphical form

Source: US Department of Energy [26]

Life Cycle Assessment (LCA)

LCA is a protocol for identifying the impacts of industrial systems from cradle-to-cradle; from the acquisition of the raw materials to technology retirement/disposal of the product. Impacts of and options for materials and energy use, recovery and waste are revealed in this assessment [27]. LCA building simulation tools include *LISA* and the *Athena Model*. Below is a brief summary of their functionality along with their inputs and outputs.

Software	Description	Input	Output
LISA	Developed in response to requests by architects for a simplified LCA tool to assist in green design. It stands for LCA in Sustainable Architecture.	Bill of materials & quantities along with possible alternative materials; work schedule ; utilization schedules	Graphical and tabular showing impact of each stage in terms of resource energy used; base material data and a bill of material quantities are also reported
Athena Model	Provides environmental data and assists with the complex evaluations required to make informed environmental choices	General description of building project including its location. Specify designs by selecting from assemblies or by entering specific quantities of individual products	Life cycle inventory (LCI) that contains estimates of environmental effects per unit of each building product.

Source: US Department of Energy [26]

Building evaluation tools for environmental impact are typically plug-ins or add-ins for traditional building modeling systems. They are also used as standalone systems by professionals from different disciplines for their purposes. However, there is a relatively new movement, Business Information Modeling (BIM), is the process of maintaining a repository of information relevant to building or construction projects through the different phases of the project lifecycle. A BIM system also aims to integrate the information systems of the different disciplines involved in the project's lifecycle; from inception to retirement [29]. A variety of tools and applications need to have the capability to support the generation of data for the facilitation of BIM technology because amount of information and the variety therein is extremely large. Examples of BIM systems are, among others, Autodesk's *Revit*, and Graphisoft's *ArchiCAD*. For different stages of a building project, BIM design tools like *Revit* and *ArchiCAD* will have different add-ins either created in-house or externally. For instance, for structural design, Revit has *Revit Structure* and for Energy Simulation it has *Green Building Studio* which was designed to be integrated with the Revit system [28].

As many building evaluation and simulation tools as there are on the market and as impressive as their functionality is, these tools are not as extensively used as would be ideal for the construction industry. Research has shown that the problem is that the greatest cost is not the acquisition of the software tools but rather the time is takes to learn and use the software. The extent of required time has been quoted as one of the main hindrances toward the pervasive use of computational building performance assessment tools by designers. The most common scenario is that modeling applications are mostly used in the later stages of design and by specialists rather than architects [24, 25].

In both conventional and green construction, it is important to integrate building simulation and building design because this will enable effective management of different technologies within the building and construction industry. Integration of building design and building simulation means reaping the full benefits of the decision support that building simulation provides by proper use of the tools on the market. The old adage "garbage in, garbage out" is applicable in the integration of building design and building simulation because if the inputs into the building simulation tools are erroneous, so will the output and this will prevent integration. Therefore, in the utilization of building simulation and evaluation tools it is necessary to take into consideration the human presence throughout the lifecycle of any given construction project and the implications thereof.

Case Study

OHSU's center for health and healing was looked at as a case study to see how these different technologies were used on an actual project. The reason why this building was looked at was because of its high LEED rating. With such a high LEED rating, there was a lot of innovative idea that had to be used to make it a green building. Some of these innovations included the following: water harvesting system to recycle all of the water that has been collected and use this gray water for janitorial purposes, flushing toilets, etc.; using natural ventilation in the stairwells; eliminating HVAC in as many areas as possible by using chilled beams and other integrated energy storage systems, using photo sensors on the shades to create electricity. The following sections discuses the utilization of those technologies in detail.

Project Overview

This project is an expansion of Oregon Health & Science University (OHSU) into Portland's developing South Waterfront. The building is a 400,000-square-foot, 16-story medical office and wellness building. In addition to a two-story wellness center, the building houses several different types of university operations, including biomedical research, clinical space, outpatient surgery and educational space [31]. The lead architect for this project was "GBD Architects", with the collaboration with "Interface Engineering". The project was completed in 2006 with LEED Platinum certification, the highest LEED Standard. In 2006 OHSU was the largest LEED Platinum certified building in the United States [33].

The developer's integrated design approach brought building team members together early on in the process, and was crucial to achieving creative and cost-effective green engineering solutions. The environmentally-innovative engineering design was achieved for less than a conventional budget for mechanical and electrical systems.

Utilization of Technology

The design of this building achieved energy efficiency exceeding Oregon Energy Code and ASHRAE requirements by 61 percent. It has also100 percent onsite rainwater reuse system. The implementation of new HVAC technologies contributed to 10 percent net reduction in budgeted HVAC and electrical capital costs ($3 million savings) [33]. This building generates 300 kW output from five microturbines, and 60 kW solar photovoltaics integrated with the south-facing window overhangs. Also the building has site-built solar thermal system for water heating.

Here is a detailed description of the technologies and strategies that were used in this project to make it the greenest building by LEED standers [32,33,34];

Water

- 100 percent onsite rainwater reuse system; rainwater reclamation system keeps all rainwater on site.
- Onsite bioreactor for sewage treatment.
- Lower-water-using fixtures for sinks, toilets, urinals and showers.
- The cooling tower and landscape irrigation systems use non-potable water from rainwater, a small amount from ground water and a large volume of treated sewage (courtesy of the bioreactor).

Energy

The building is 61 percent more energy efficient than Oregon Energy Code requirements and LEED standards.

Onsite Power:

- A Central Utility Plant (CUP) provides electricity and thermal energy for several of the planned buildings in this area; it is powered by energy-efficient microturbines.
- Building-integrated solar electric panels on the building's south-facing sunshades, with a total of 60 kW of photovoltaic modules.
- A large 6,000-square-foot solar air heating system that uses low-iron glass in front on the south-facing wall of the 15th and 16th stories.

HVAC:

- Individually tailored heating and cooling strategies to different portions of the building, and use of radiant heating/cooling and natural ventilation instead of traditional air conditioning and forced ventilation.
- Right size HVAC system: the building's energy-efficient windows, extra wall insulation, concrete floors at ground level and other features provided a solid envelope to maintain a mild temperature range. An HVAC system with fewer safety factors for peak heating and cooling loads was selected.
- Sensors and controls: inside meeting rooms, carbon dioxide sensors (CO_2 concentration is a sign of human occupants) reduce ventilation systems when the spaces are empty.

Lighting:

The following lighting technologies have helped reduce electrical energy use by 16 percent;

- Photoelectric sensors turn lights on and off according to the amount of natural daylight in a room. Daylighting is expected to save $20,000 per year in energy costs.
- Occupancy sensors in stairwells switch lighting on and off to follow an occupant.
- Perimeter offices with occupancy sensors have daylighting control, keeping room lighting off when there is sufficient natural light.

Chilled Beams:

Implementing this technology has contributed to 20 to 30 percent energy saving over traditional systems. It has also allowed the HVAC system to be a third of the size compared to conventional design.

Integrated Energy Storage Systems:

In this building, hot-water storage tank contains heat from the microturbines; a warm-water tank uses energy from the solar thermal collector and heat recovered from the heat pump chiller; a cold-water storage tank uses all the cool water from the recovered rainwater and pumped groundwater.

Renewable Energy

In regard to the implementation of renewable energy sources, the following technologies were used in this project;

Building-integrated Photovoltaics:

- The sunshades on the south facade keep the sun off the windows in the summer and lower the HVAC system requirements for cooling, while creating a free surface for solar electricity generating panels. The annual output of this system is 66,000 kwh.

Solar air heater:

The solar electricity generation panels on the 15th and 16th floors create a giant solar air heater, 190 feet long by 32 feet high, to preheat water for the building.

Indoor Air Quality

- Natural ventilation in stairwells.
- Displacement ventilation systems in exam rooms to increase patient comfort.

Cost and Savings

The total cost for this project is about $145,000,000 including land development and two-block underground parking garage. Out of that the total, the greening cost was about $1,800,000 which includes $500,000 in Photovoltaic system and $1,300,000 in energy efficient upgrades including solar air heaters.

The implementation of green technologies resulted in electricity cost saving of $660,000 a year. More than 5,500,000 gallons of water a year is collected each year, which is valued at $40,000 yearly saving. Also the pollution reduction of this building is 12% of CO_2, 38% of NOx, and 38% of SOx.

Future Implications

The demand for green construction technology is increasing. The U.S government, for example, has planned for the country to be net zero by 2030. The strategy to achieve this is by making sure all new buildings produce zero emission. Second, Improve new buildings efficiency by 50 percent. Finally, improve existing building efficiency by 25 percent.

The 2030 goal is a very impetus goal and it has its own challenges. The first challenge as Dr. Sailor said is political. It is up to politicians if they want to make it happen they will. As in the same way they put a man in the moon, this at the time was thought impossible. The second challenge is that 85 percent of the buildings that we are using today will be in use by 2030, and that make it very difficult to achieve.

At the same time green technologies will continue to grow in response to the current demand. Many innovations are coming out every year in this industry, and new standers are raising the bar. As of this year, LEED introduced the new LEED stander 3.0. The score is out of 110, and it has the same four certificating categories.

The challenge that will remain in regard to green technologies will be efficiency and cost. As of today, it is very expensive to build a green building, and many that are built have not been as efficient as expected. Many buildings here in Portland for example were designed to be LEED gold or platinum, but when built it was very difficult to achieve this as a result of efficiency and cost of green technology [34].

Conclusion

In conclusion, the field of Green Construction is studied and researched today in such a away that it encompasses all processes and materials involved in sustainable building construction from cradle to cradle – from raw material acquisition to building construction, operation and subsequent retirement/disposal. Throughout this lifecycle, there will always be a human element which can make or break the project. Whether it be in the form of expertise or political will. Research has led to new technologies, which has led to new products that have continually taken this industry to greater heights.

Certain aspects of green construction, such as green roofs, are particularly new in the U.S. and one of the reasons for this may be that contractors are now, more than ever, more willing to implement technologies that have more proven successes elsewhere. Furthermore, from a purely commercial point of view, the now widespread concern about the issue of global warming has made the current era the right time to introduce innovations that promote sustainability.

Science as the basis for the technology that supports green construction is a common thread in this paper; the nautilus design in the Biomimicry section, green roofs in the Mechanical section, filtration systems in the Chemical section, and Computer Science in the Software section. As further research is carried out in this industry, a deeper understanding of the science underlying these different technologies is essential to innovations that will make this industry more efficient and effective.

Research and Development (R&D) is an essential component to this industry especially because it is relatively new. History has shown that political will goes a long way in the progression of technology. For instance, when President Kennedy declared that the U.S. will put a man on the moon in ten years [30], it seemed like a nearly impossible task but as the President, he had the power to beat all the obstacles that would have prevented the fulfillment of this goal.

There are also certain conflicts within this industry. For instance, although solar energy is considered sustainable, the manufacturing process for the silicon wafers used to make solar panels produces large amounts of noxious chemicals. This is an example of how much research is still needed in this industry as there are still a lot of unknowns.

There are also a lot of potential errors in performance as many of the technologies, because they have not been used long enough to be effective; the lack of integration between building design and building simulation exemplifies this truth.

The cost of Green Construction is high relative to conventional construction. One basic example would be to compare the cost of construction using concrete to that using steel or platinum. The latter are clearly more expensive despite the fact that they are more environmentally friendly and seismically stable. As demonstrated by the OHSU case study, return on investment is very slow – with only about $700,000 savings on energy and water after a total investment of $145,000,000. It is of course important to point out that the pollution reduction of the building is difficult to quantify and may, thus depress the real return on investment. With increasing research in Green Construction and increased use of the methods therein, one can only be hopeful that the cost will come down.

Finally it is important to remember that there is a human element at every stage of a building project's lifecycle and so there is always room for error in the implementation of technologies. Therefore, effective management of technology is the key to sustainable growth in the Green Construction industry.

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Appendix 1

Interview with David Sailor

Mech. Engr. At P.S.U.

Green Roofs

For the heat island credit (LEED), related to green roofs, is triggered when at least 50% of the roof area uses a green roof.

Green Roofs and photovoltaic sensors are competing technologies, because buildings that want to generate a lot of electricity on site one of the best places to do this is the roof top with photovoltaic sensors.

One question that is being researched is if you can get a better green roof by irrigating it.

Green Roofs have been around for a long time, why has the demand for these increased?

In the U.S. they have not been around for that long of a time, there has been a lot of work on this throughout Europe for the past few decades' even centuries. I think that there is a growing interest in part because of the variety of benefits that they can provide. The benefits range from urban storm water mitigation to urban heat island aspects energy for energy consumption. Building contractors and owners are willing to take more risk now that there are more examples of successful building. They are more comfortable putting this on their building.

When a bibliometrics search was done on Green Roofs and Eco Roofs there were not that many references hits. Do you consider the technology for Green Roofs to be ground breaking and relatively new?

From the research standpoint it is still relatively new. Green roofs have been around for centuries latterly, as a mechanism for insulating the structure from the outside environment. But I do think that the research is still resent, more and more there are people who are trying to quantify what are the benefits to the building in terms of energy consumption, what are the benefits for storm water reduction, storm water quality (what coming down the down spout). This is also a reason why you do not see green roofs as much because there are a lot of unknowns. So the research is now starting to answer these questions.

How has biological research lead to technology innovation relating to Green Roofs?

When you put vegetation on a roof top, there are challenges, because you typically have thin soil, you tend to not want to put too much organic matter in your soil because you do not want to have some of the runoff that might result from fertilizers on your roof top. So there is a lot of work going on to understand what types of plant communities do well in thin soils on roof tops.

What types of plants can survive.

People who are building the building do not really care about what types of plants are on the roof, they just care about how much weight results from this. While people who are looking into the energy savings, you do have to take into account what type of vegetation is up there, to understand the energy balance.

There is more of a need now to understand what types of plants you are putting up there and how that is going to impact the energy balance.

What types of benefits are there with using EnergyPlus? It is already part of D.O.E.s and there standard are there any other benefits?

Designers, Architects, ect., can estimate the impacts of different designers decisions in affecting the energy consumption of the building to start with. Are hope eventually is to take this type of information and merge it with information about the storm water runoff retention capabilities and maybe urban heat island capabilities as well.

Are there any shortfalls with this program that should be fixed?

One problem with our model is that our plants never die.

Another problem with this model is that if you add water to the green roof you cannot model how lush the plants are.

It is a useful tool to have, but it has its limitations.

There are some limitations such as the way that I created the green roof module, that part of the EnergyPlus Software, I only allow for one type of vegetation or one type of green roof on any building. So in a single simulation you cannot model the effect of having half of the roof top having lush vegetation and deep soil, and the other with sedum and thin soil. You cannot do this right now.

One of the big limitations right now is that it does not model plant health and growth. If you have a deciduas plant species up there it does not have plants' loosing there leafs and this sort of thing. You can simulate these types of effects by isolating the different parts of the years and model setting up different conditions for the pant in each interval. You can still model these characteristics but there are just not parts of the model package yet.

On the Broadway Building at P.S.U. the plant vegetation used was from the natural habitat around Portland, why was this used?

It is fairly common that people will use the native species, this is because they do not want to introduce invasive species to an area, you want to attract the native species of animals from bugs to birds, ect. So it makes since to use native species and plants that native animals are used to.

Heat Islands

It seems that Heat Islands only focuses on applications geared toward the summer, why is this? For areas like Portland where it is a temperate temperature what should be done?

The motivation for really caring about the urban heat island is typically driven by summer time conditions. It is also not just extreme climates; in many cities across the U.S. you have millions of people living in the city who experience extreme heat conditions in the summer. The urban heat island will increase their air conditioning consumption, it will increase in their risk for heat related mortality and mobility, and it will increase air pollution. It just has a host of impacts that happen in the summer time that are particularly detrimental. In the winter time the heat island is not that of a big issue because you will actually save on energy consumption of heating. So we tend to focus on the summer time because that is where the problem is.

In Portland there is a heat island but it is not that big of an issue. We did a study that compared Huston with Portland. In Huston virtually everybody has easy access to air conditioning. In Portland we occasionally have heat waves where the temperature reaches 100 to 105^{o} F, for two are three days in a row and half of the population does not have access to air conditioning in their homes. So there is much more of a higher vulnerability in these more temperate climates to these extreme events, because people are not accumulated to these temperatures and their bodies are not able to handle these high temperatures. So people do not have the best practices to extreme heat in terms of things like hydration, shelter, ect. So there are risk factors for places like Portland.

Has there been a large scale use of lowering the albedo level across the nation yet?

It is very much climate dependent, for places like California, it is actually a state requirement for buildings with a low slope to have a low albedo level. In many other hot environments it makes a lot of since. You can put a white membrane on a roof that does not cost you any more money compared to a black one. In certain climates it just makes a lot of since.

It is always going to hurt you on your heating bill and it will always save you on your heating bill.

It seems that your study has been focused on commercial areas, has any study been preformed for the residential areas? If there has what types of benefits are resulting from this study?

For heat island mitigation it is easier to have a larger impact on roofs that have a large flat surface.

A problem with the residential area is that houses that have a sloped roof, people do not want to have a high albedo on it. So the residential sector has not been implementing high albedo roofs vary widely. But there are new technologies that have been developed, ne types of coatings where the pigment in the coating uses something other than carbon black as a pigment. Chemically you can create a coating that might be gray or light brown, a more common type of roof top color, that to the naked eye, the visible spectrum is not much reflectivity so there is not a glare concern. But in terms of integration over the solar spectrum it is reflecting a lot of the energy outside of the visible spectrum. As they bring the cost down for these types of coatings it should greatly affect the residential market.

General Questions

There are many high performance buildings that on paper and on the computer look like they are extremely efficient, low energy consumers, but when they are built and occupied they do not perform as expected. Part of this is how mechanical equipment actually functions, part of it is integration of systems, and part of it is that you have actual human beings in the space. So we are trying to bring the expertise necessary to understand all of the aspects of building performance.

Other than Heat Islands and Green Roofs, what other types of studies are being done at PSU?

Innovative glazing materials for windows that will be better at letting light in when you want the visible light for day lighting but keeping out the heat or keeping the heat inside the building.

Innovative materials that you can embed into dry wall that will help absorb energy and store it without raising the temperature of the wall. Then this energy would be put back into the room when the air temperature changes.

Do you think that we will be able to reach the 2030 goal of having every building being self sustainable? If so why? If not, what is limiting us from reaching this goal?

Political will, it is kind of like how Kennedy said that we will put someone on the moon in the next ten years. Everybody scoffed at that and said that there is no way that we can do that. With the right political will and investment you can do it.

Making certain types of buildings net zero, does not seem practical to do it, with having net zero on site to do it. This is especially true when you start to talk about tall sky scrapers in cities with relatively low solar access and very high heating and cooling advents. But to make it fairly common that buildings are built with net zero, I think that this is a doable goal by 2030.

Would this just be new construction?

There is the dilemma; approximately 85% of the buildings we will still be using by the year 2030 are already here. So much of the new construction might be net zero by 2030, but what about the existing buildings? If you only impact the new construction you are missing a huge opportunity, because that 85% is much more than the total 85% of the energy consumption. Some of them are real energy hogs because they are not built for energy efficiency.

Is it realistic that some of these buildings might be retrofitted to meet these standards?

I think that this is where one of the biggest opportunities is, is in major renovations and retrofits to the existing building stock.

Do you think that it would be economical to do this? People do not see the reason to do this; they are only looking at the sticker price.

We are not really paying the true cost of energy right now, so energy is really quite cheap in this country right now, and thus it does not make economical since right now so people are not going to do it. But when you take into things like affecting the environment and things along this nature, it may become more justified. This is more along political lines though.

Large companies are paying a lot more on annual salaries right now than they do in energy expenses. As long as the energy part is just a blimp on their screen they are not really going to be concerned with that. When they start to make the connections between green buildings affecting the productivity of the people within the building, the social dimension, they might start realizing that by implementing some features that make it more energy efficient, it does not affect our bottom line very much. But if this energy efficiency comes with an increase of productivity, even if this is only two to three percent and hard to measure, this might be well worth the extra cost of the retrofit.