History of Passive Solar Energy

Scott Barber
East Carolina University
Faculty Mentor: Michael Behm
East Carolina University

ABSTRACT

Passive solar design, an idea within the growing trend of green building, is a creative way to use the sun to our advantage, both for heating and cooling, based on the design of buildings. As green building has continued to become more popular, many changes have been made to make the design and construction of our buildings more environmentally and economically sustainable. This review focuses on the development in passive solar applications, from its earliest appearances in ancient Greek buildings to current designs that take advantage of radiation convection or acrylic panels. There have been many passive solar developments that can be explored, and the innovative technology today has brought about great advancements in the past few decades alone. This review presents a compilation of information from a variety of sources that provide knowledge regarding the history of passive solar energy. As the popularity of green building continues to grow, it is essential to develop an understanding of passive solar design, and other green building techniques, in order to be equipped for the years to come.

Passive solar systems are used to "collect, store and distribute thermal energy by natural radiation, conduction and convection through sophisticated design and wise selection of building materials" [9]. This definition, provided by J.K. Paul, sufficiently explains that the idea of passive solar energy is the use of natural processes, such as radiation, conduction, and convection, to distribute thermal heat provided by the sun. Passive solar energy also involves blocking the sun's rays in order to provide cooling during the summer. Incorporating solar energy into our buildings will decrease the amount of money we spend on energy as well as extend the time other sources of energy will last.

Due to increasing oil prices, rising gas prices have become a common sight not only in the United States, but around the world. The exploitation and misuse of our natural resources is rapidly depleting our oil and natural gas. This type of deterioration is not only evident in natural gas, but also in many other common sources of energy. Though many are aware of the decreasing amount of oil, most people assume there is an endless supply of coal, nuclear, and other energy sources. It has been estimated that there is enough coal to last about 250 more years[14], enough oil to last approximately 44 years[5], and nuclear fuel to last 23 years[12], if the cost is kept somewhat higher. Even if these numbers are a low estimate, and enough energy sources remain for several more centuries, there is still a need to find cleaner sources of energy. What many people are unaware of is the damage that our current energy sources cause to the environment[4]. The pollution and other byproducts of manufacturing usable energy from these raw materials have dramatically affected not only the atmospheric quality, but they have also damaged the surrounding ecosystems, whether they are forests, prairielands, or water habitats. Ron Jones, an architectural expert for sustainable building, explains that humans have begun to further explore and understand the relationship between the built environment and the natural environment. In the past, we simply were concerned about the effect of nature on buildings, but now are realizing the impact our buildings have on the environment. This is the key to sustainable design[6].

There is a plethora of renewable energy sources that provide energy that is much better for the environment. While the mining and burning of coal and uranium leads to smog, acid rain, and air toxins, renewable energy, including solar, wind, hydropower, geothermal, or even renewable materials such as agricultural products or biomass, results in little, if any, pollution. These types of renewable sources are becoming a pivotal aspect of the increasingly popular "green" movement. There are three parts of being green: being acceptable economically, ecologically, and socially. These three pillars make up the sustainability movement, and help direct decisions so that processes and materials used are suitable in each of these areas. For example, when installing wind turbines, to completely fit within sustainability, one must take into consideration these three ideas to ensure that the turbines will be economically efficient, environmentally friendly, and socially acceptable. While a wide variety of renewable sources exist, they are not developed enough currently to provide materials and systems that are beneficial within the three pillars of sustainability. However, one type of renewable energy does have the necessary progress to be used and still be considered sustainable: passive solar energy. While many people are aware of active solar energy systems, such as solar panels, passive solar energy is a division of solar energy that uses the sun's energy in a more natural manner. It is also helpful to understand specific savings in cost for buildings that use passive solar energy. According to a document provided by Appalachian State University, a passive solar home could save as much as $160 per year by using simply using movable insulation and low-emissivity glass, glass that radiates low levels of radiant thermal energy [11].

In this paper, I overview the history of passive solar design as well as review and analyze technological information regarding the use of solar energy. The goal of this review is to inform the reader of historical passive solar energy uses and to explain in greater detail what passive solar energy is and how it is applied.

CATEGORIZATION OF PASSIVE SYSTEMS

To have a better understanding of passive solar energy, it is helpful to know how to categorize passive systems used for this type of solar energy. While there are specific techniques and systems that use the sun's energy in a passive way, they are all defined as being either direct gain, indirect gain, or isolated gain.

Direct gain is the simplest application of passive solar energy, where the space of the building is directly heated by the sunlight, which most often enters through windows within the south-facing wall for buildings in the northern hemisphere[7]. Ideally, in this approach, the materials within that space ought to be capable of storing heat and the air flow throughout the room should distribute the heat. A representation of direct gain is shown in Figure 1, which also depicts the difference of the angle of the sun during the summer and winter, and how an overhang can be incorporated into the building design for further temperature control.

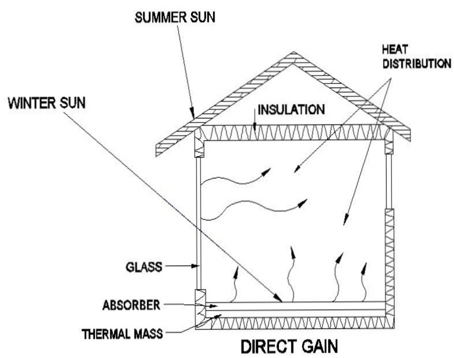

Fig. 1. Direct gain passive solar energy.

For indirect gain, sunlight is most often received by a south-facing wall, and as air moves throughout the internal space, the heat will then be transferred from the wall to the living space[7]. For increased control of indoor temperature, ventilation at the top and bottom of the wall or other thermal mass is included, assisting in regulating the temperature. Figure 2 clearly displays indirect gain, the use of a thermal mass for solar heat gain, as well as vents integrated into the thermal mass for air circulation and heat distribution.

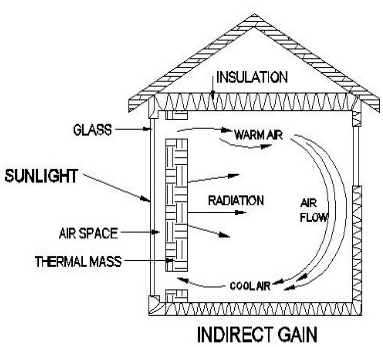

Fig. 2. Indirect passive solar energy. Thermal wall with ventilation for airflow and temperature regulation.

Isolated gain, depicted in Figure 3, uses solar collection and thermal storage that are separate from the actual living space, moving heat to the living space through natural or forced convection. Ventilation is also essential in this method of passive solar heat gain. An advantage to isolated gain systems is that they can be added to new and existing buildings[2].

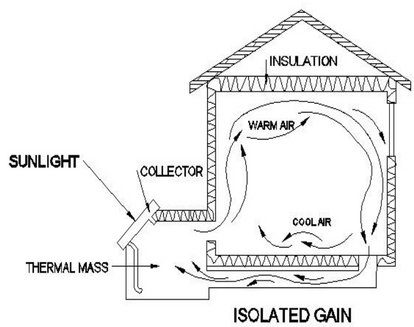

Fig. 3. Isolated gain passive solar energy.

Regardless of the type of heat gain utilized, passive solar energy provides heat at little to no cost, aside from the slight variations in the design and construction of the building.

HISTORICAL APPEARANCES OF PASSIVE SOLAR

Solar power has benefited civilizations for centuries, and the knowledge from our past provides foundational understanding of the sun's energy to bring about our current understanding of solar power. The earliest known application of solar energy arose during the 15th century B.C. by the Egyptian ruler Amenkotep III, who "supposedly possessed 'sounding statues' that operated when the air in their base pedestals expanded after exposure to sunlight"[3]. Though this was merely an accomplishment of aesthetic value, solar energy has also been used to distill water as well as dehydrate agricultural plants. Solar energy has been used in even more advanced, practical ways by many civilizations to provide heat for homes, light fires, and even cauterize wounds. In the 5th century A.D., Socrates realized that "in houses that look toward the south, the sun penetrates the portico in winter, while in summer the path of the sun is right over our heads and above the roof so that there is shade"[8], and that initiated the use of solar energy to heat homes.

Though the first recorded application of solar energy is in the 15th century B.C., the next appearance wasn't for several hundred years, where the historian, Plutarch, documented that virgins used cone-shaped metal objects to start ritual fires during the 7th and 8th centuries B.C.[3]. During this time the sun was used to distill water and dehydrate agricultural plants. A famous use of solar energy, while the event is still surrounded with reservations and disbelief, occurred in 212 B.C., when Archimedes used a "burning mirror" to set invading Roman ships on fire. A similar story was recorded in the 12th century, where Proclus, a Greek, supposedly accomplished this achievement during the siege of Constantinople when the Bitellius fleet was invading, using many mirrors.

While there is no sure way to know whether or not these feats happened, the recording of this event sparked much curiosity, and soon more applications of the sun's energy were being recorded in history. For example, in 77 A.D. Romans used "burning glasses" to cauterize wounds and light fires[3]. Another one of the earliest applications of passive solar energy was in the Roman atrium and heated bathhouses in the first through the fourth centuries, where large south facing windows let in the sun's warmth to heat the pool[9]. Solar energy became so well-known in the 6th century A.D., that the Justinian Code commenced "sun rights" in order to guarantee everyone would have access to the sun. The last known use of solar energy before the 1700s appears in North America. The Anasazi Native Americans built their homes in the side of the cliffs in what is now known as the Colorado Plateau, where Utah, Colorado, Arizona, and New Mexico meet[9]. These south-facing buildings were placed within the side of the cliff to avoid the sun in the summer, but make use of the sun during the winter. It is clear that there was an early understanding of using the sun for energy, and this knowledge and technology surrounding it increased significantly beginning in the seventeenth century.

Up to that point in history, through the 1200s, passive solar energy was used by Egyptians, Greeks, Persians, Hindus, and the Native Americans, following ancient architectural teachings of Aristotle, Xenophon, and Vitruvius [9]. In the ancient historical appearances of passive solar energy uses, the architecture was geared towards using the sun and wind to alleviate the extremes of the climate, but due to a lack of glass, they were unable to utilize the sun to the extent we can today. However, though most ancient civilizations lacked glass and other technology that we use today, they still made significant progress and provided understanding and a good foundation for future developments regarding the use of solar energy.

Beginning in the 17th century, interest grew in regards to using the sun as an energy source, and though there was not a large amount of development within passive solar techniques, significant progress was made in active solar systems. The increased awareness of solar energy brought about by the experimentation with solar energy served also to make people conscious of the use of solar energy passively, as well, though there isn't as much historical recording of passive solar energy during this time. In regards to active solar energy systems, the first "solar engine" was invented in 1615 by Salomon de Caux. This engine used glass lenses to heat up an airtight metal vessel with water and air to produce a small water fountain[3]. Though this lacked practical use, it is significant because it was the first published documentation of solar energy after the fall of the Roman Empire. Also in the 17th century, physicist Athanasius Kirchas experimented with starting fire with mirrors, and German mathematician Tschirnhaus worked with lens-type items to concentrate solar energy to melt various materials[3]. Overall, the 17th century included various experiments from different specialists who sought practical applications of solar energy.

In the 18th century, there was more experimentation from many various professionals around the world. French scientist George Buffon worked to determine whether or not the Archimedean feat could have been accomplished, and determined that setting ships on fire was possible, but not very probable considering the lack of technology in 212 B.C.[3]. Another Frenchman, Claude Poillet, provided significant information that would assist in the development and application of both active and passive solar energy. He determined the intensity of the sun in reference to the geographical position, and it is this association which has been regarded "at least as important in solar utilization as the hardware itself"[3]. It was in 1767, just a few decades later, that the first solar collector was invented, built by Horace de Saussure, a Swiss scientist. This collector was used to heat food, and was used by Sir John Herschel in the 1830s, during his expedition in South Africa[13]. There continued to be a variety of research and investigation in regards to solar energy during this time, all providing more information that would serve useful in years to come.

It was in the late 19th century that passive solar energy began appearing more often and in more noteworthy means. In 1880, theories surrounding solar houses began to appear, and it was in Salem, Massachusetts that the idea of a glazed, south-facing wall, as well as incorporating the requirements for air flow between the glazing and the wall first arose. Not only that, but professor E.L. Morse was approved for a patent "for the combination of a dark colored massive wall, an air space, glazing…and adjustable dampers by which the flow of air could be controlled"[9].

A few years later, in 1896, the thermosyphon water heater was invented, the oldest and most widely used passive solar device in the world, which was utilized in World War I in Southern California to provide hot water to army camps[9]. Many other southern states adopted this technology, as well as Japan and Australia, but the extension of natural gas lines and the cheap availability of electricity resulted in a nearly complete elimination of its use. However, due to increased prices in other energy sources for providing hot water, this device and its "active but similar offspring," and the forced circulation solar water heater, are beginning to be used more[9]. These new developments provided more information, but also created specific ways that passive solar energy could be implemented into people's daily lives. For example, a home built in Massachusetts was one of the greatest steps in passive solar design during the last few centuries, providing a concrete and successful use of passive solar energy. Overall, the 1800s provided more research in solar energy than perhaps any other time in history. However, the following centuries resulted in a greater diversification of the applications and uses of solar energy.

MODERN DEVELOPMENTS

Since the twentieth century, there has been a great variety of fairly modern passive solar developments. Though the deliberate practice of using solar energy for heating within buildings was apparently forgotten outside of agricultural, the 1930s reintroduced this practice in the relatively colder climate of Minnesota[1]. The sudden increase in the application of and interest in passive solar energy was a result of sealed, insulating windows becoming available at a much more reasonable cost. Due to the necessity of windows within the application of many passive solar techniques, easily available windows allowed passive solar methods to appear in residential architecture just before World War II[9]. The Keck brothers in Chicago were forerunners within the new appearances of passive solar energy, providing prefabricated buildings in the 1940s. These buildings used large, south-facing windows with overhangs to admit sunshine in the winter but block it in the summer months. They also included flat roofs that were made to be flooded during the summer to decrease the amount of solar heat gain[9].

Though these and similar houses were being designed and constructed, they lacked the full potential and were less effective, mainly because the common heating and cooling systems were readily available at a much lower cost. Another notable progression within solar energy use in homes was the book entitled Your Solar House, funded by Libbey-Owens-Ford Glass Company. This book included forty-eight designs for homes to utilize direct gain solar energy, one design for each state within the United States at that time[9]. Again, these designs were not ideal applications of solar energy, primarily because there was no consistent way to control temperature within the buildings. In various adaptations and improvements that were made to these designs, double glazing, windows that could be opened, and ventilating fans were used to maintain comfort. Unfortunately, there was a slight break in research and development concerning solar energy during World War II, even though there were still companies practicing these methods.

After World War II, despite the revival of interest regarding solar heating, most people were focused more on active systems for solar energy and therefore passive solar heating was largely neglected. The American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE), however, continued to research the gain of solar heat through window placement, which has provided foundational information for today's strategies for determining solar heat gain through windows, and has resulted in multiple direct gain passive solar houses in New Mexico[9].

These homes implemented newer technology which improved them significantly from their fairly inefficient predecessors built in the 1930s and 1940s. For example fairly consistent temperatures were gained through concrete or adobe floors which absorb heat. Also, movable insulation protected the house in times of exceptionally cold weather or when there were extended days where clouds blocked the sun[9]. The improvements in these structures significantly increased their practicality and effectiveness.

In the decades following, there were continued discoveries and inventions regarding solar energy. In 1954 photovoltaic technology was first revealed, as Daryl Chapin, Calvin Fuller, and Gerald Pearson invented the first solar cell that converted energy from the sun to provide electrical power. The following year, Western Electric began selling licenses for silicon photovoltaic technologies. It was during this time that architect Frank Bridgers designed the first commercial office building that used solar water heating and other passive solar designs[13]. It is worth noting that these passive solar systems are still in operation within this building today, and this office building has been recognized in the National Historic Register as the world's first solar heated office building.

Since these improvements, the most noteworthy addition to passive solar energy is the Trombe wall. Developed by Frenchman Felix Trombe, based on the work of Edward Morse in the 1880s, this wall faces the sun and essentially absorbs the sun's heat and releases it inside the building at night[9]. Aside from slight alterations, most passive solar techniques have remained the same and have only varied in regards to application. Figure 4 shows a modified Trombe wall that utilizes a glazing material to collect solar heat and vents to provide air flow and distribute the heat to the interior room. This type of Trombe wall is a very efficient way to take advantage of passive solar energy.

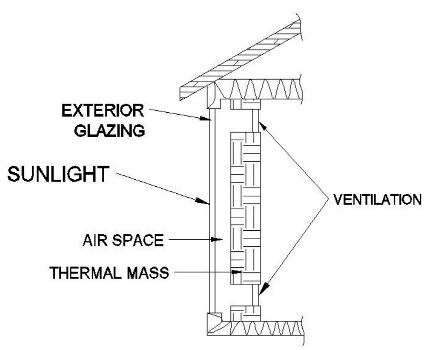

Fig. 4. Modified Trombe wall using exterior glazing and air vents for air flow.

A noteworthy aspect of passive solar design is the many programs and organizations devoted to encouraging, monitoring, and rewarding sustainable building. In 1985, Austin Energy, located in Austin, Texas, was the first residential energy efficiency program[6]. In 1991, this organization further developed and became known as Austin Energy Green Building®. Since that time, many more programs have begun, such as the Advanced Energy Corporation located in Raleigh, NC, the Southface Energy Institute in Atlanta, GA, and the Solar Living Institute in Hopland, CA. In 1995, the United States Environmental Protection Agency began the Energy Star program, which evaluates the energy use and efficiency of buildings. Since the Energy Star program is limited to energy, the United States Green Building Council (USGBC) was founded in 1993 and within that, the Leadership in Energy and Environmental Design (LEED) program was founded in 1998[6]. These programs have proved a key role in encouraging and rewarding sustainable design, including passive solar energy practices.

PASSIVE SOLAR APPROACHES

Although there are many different aspects of passive solar energy as well as the three pillars for producing sustainable passive solar energy, there are five basic approaches to forming these types of passive systems: direct gain, thermal storage walls, solar greenhouses, roof ponds, or convection loops. These techniques can be either direct gain, indirect gain, or isolated gain, based on how they collect, store, and transmit thermal energy [9]. These methods are a result of the extensive research and advancements throughout many centuries, bringing us to the understanding we have today, allowing us to use the sun's energy efficiently and responsibly.

Direct gain is the simplest application of passive solar energy, and as such is the most popular. Direct gain is beneficial because it is not only simple, but it also has a relatively low cost. However, direct gain struggles because it cannot control temperature as effectively due to of a lack of thermal storage. Other potential problems that may arise include undesirable lighting during the day such as glares, as well as discoloring of fabrics due to extensive ultraviolet rays[2].

The second common approach to passive solar energy involves using a thermal storage wall, which essentially uses a material that absorbs the sun's heat after it has passed through the glazing. The wall may be black or another dark color to assist in its absorbing, or it may even consist of water held in masonry or other containers[2]. Regardless of the absorbing material, its purpose is to absorb the temperature and release it into the interior room. This assists in controlling temperature and reducing temperature extremes, as well as reducing the negative effects of direct gain: glare or undesirable lighting and material damage due to the ultraviolet light. While direct gain can heat up a room much quicker, it is much more difficult to control, which is a benefit of using a thermal storage wall. Often, windows are included in this wall to combine direct gain with the thermal storage to incorporate the benefits of both[7].

Using a roof pond is the third common approach to passive solar techniques[2]. It may or may not include the physical presence of water on the roof, but where there is not water present, movable insulation is required on the roof. Essentially, this technique relies on gathering solar heat through the roof, but with insulation that prevents too much heat from collecting during the hotter summer months [2]. There have also been studies and research in New Mexico and Arizona, testing various active and passive systems to control the amount of heat transferred through the roof. This type of system would be used for a flat roof, ideally, and could serve beneficial for both heating and cooling by adding or removing the insulation during summer and winter, or day and night.

The final approach for passive solar techniques is the convective loop, which uses a thermo siphon, a machine that circulates water, to move heat from the collection point to a storage area. Water heaters often use this idea, as it is very inexpensive and reliable, more so than many other types of water heaters commonly known. This system works well without needing pumps or controls[9]. Air convention loops often combine passive collection/storage with active distribution to provide a simple but effective system to provide temperature control for a building.

Overall, these five types of applications of passive solar energy can be very beneficial to include in many different climates and situations. When applying these ideas to buildings, it is important to be aware of the strengths and weaknesses of each of these applications. It also may be very feasible to combine a variety of these approaches in order to utilize their strengths and develop a well-rounded passive solar building.

The majority of all passive solar energy techniques are applied during the planning and construction process of the buildings, because the most important aspect of a building is its location and direction. However, there are a few options that provide heating from solar energy for pre-existing buildings. By adding larger windows or double-glazed, low-emittance windows on the south wall, passive solar energy can be utilized. The double-glazed, low-emittance windows have the ability to allow heat to enter into the building but reduce the amount of heat lost to the outside. Also, planting deciduous trees, trees that shed their leaves in the winter, on the south side of a home will provide shade from the sun during the summer but allow the sunlight to enter into the windows during the winter. Blocking in windows on the north side of a home may also assist in solar heating, though doing so may not be aesthetically pleasing.

PASSIVE SOLAR ENERGY: IS IT WORTH IT?

While passive solar energy is growing in popularity within the green movement and has improved significantly in the last few decades, there are still doubts surrounding its viability and effectiveness. The primary arguments that are made in favor of using passive solar energy are divided into economic, architectural, and comfort/health categories. In general, passive solar energy is very beneficial because it is inexpensive and has little, if any, impact on the environment.

When observing the economic aspects of passive solar design, it is important to remember that each building is different, depending on construction and materials used. However, the benefit to passive solar energy, as opposed to active solar energy or other types of renewable sources, is that it requires no additional cost for upkeep; the costs are the same as the general maintenance costs of any building. It is possible to save money long-term simply by taking passive solar systems into consideration for the design process[6]. Changing the direction of the structure alone, in order to gain more heat from the sun on the southern part of the building, can make a huge difference in collecting solar heat. Essentially, passive solar energy only requires a slight increase in cost, if any increase at all, to incorporate these systems into the design and construction of the building.

In terms of temperature within the building, some people may be hesitant to use this technology, mainly because it isn't easy to control the temperature of a room which is dependent on passive solar for heating or cooling. However, pairing up passive solar aspects with a back-up heating system, shading devices or operable windows will greatly increase the amount of control one has in regards to temperature[2]. Also, passive solar heating also maintains a warmer floor, which is desirable. Most heating systems used today can lead to large floor-to-ceiling temperature differences, resulting in discomfort at the floor level. On the contrary, passive solar systems use materials that absorb heat, and therefore the floor is warmer and more comfortable[2].

One of the greatest attractions of passive solar energy is the fact that it is very environmentally friendly; it is a renewable energy source and does no damage to the environment around it[6]. By using passive solar energy rather than a common heating or cooling system, there is a great reduction in the consumption of fossil fuels and the production greenhouse gases and other pollutants[6]. Overall, passive solar energy has few disadvantages and its advantages are both economical and environmentally friendly.

FUTURE TRENDS

While there has been a dramatic amount of progress and development throughout history regarding passive solar energy, by observing where technology is today, one can only wonder how much more progress can be made. While there certainly will be improvements in materials, it appears that the techniques have currently reached a plateau. However, when asked "What is it that we really require from scientists and technologists?" economist E.F. Schumacher provided guidance into the improvements of passive solar energy: "We need methods and equipment which have the following characteristics: they are cheap enough so that they are accessible to virtually everyone, they are suitable for small scale applications, they are compatible with man's need for creativity, and they are not heavily dependent on natural resources"[10]. Passive solar energy certainly has the potential for meeting these requirements.

The design of passive solar buildings, based on the materials and technologies available today, will remain consistent for the next several decades. The strategies and techniques being used today will be replicated in various ways depending on location and availability to maximize the benefits of passive solar energy. One can assume that when new technologies arrive, the design of passive solar buildings will adapt to incorporate them to maximize their efficiency. However, the specific design for buildings regarding passive solar energy has climaxed for the present time.

The further development of passive solar energy is reliant on new technologies and the development of more appropriate, efficient resources. One of the newest developments that will continue to grow and improve passive solar use involves window glazing. Low-emittance coatings, known as low-E coatings, are metallic oxide films that are installed on windows to reduce from within the building while still allowing solar heat gain. These coatings do not affect the visual aesthetics of the window, yet provide valuable benefits. There are also double-glazed windows filled with argon gas, which provide the same benefits as the coatings on the windows and can be used together to increase efficiency. As these technologies continue to improve, passive solar energy will become more beneficial and effective.

It is also important, however, to recognize the role that green building programs will serve in the continuation and expansion of passive solar practices. Certifications and recognition within these programs are available for the buildings being constructed, the professionals who design, build, and remodel those buildings, and the products used for the buildings as well[6]. With this in mind, passive solar practices within sustainable design will become more common, and industry leaders around the world will incorporate sustainable practices. It is important for the future of passive solar design that those involved in the design and construction of buildings to be certified in sustainable design, for resources and products used to be sustainable, and as a result, the structures will be more sustainable as well.

CONCLUSION

Throughout history, mankind has benefited from and worked to harness the sun's energy in order to create a more enjoyable living space and save energy. Solar energy has been used for centuries and has only improved with time, as researchers and scientists have developed processes and materials to improve the quality and effectiveness of solar energy. Using solar energy, specifically passive solar energy, is a very cost efficient way to take steps towards sustainability, and as the green movement continues to develop and expand, passive solar techniques will be utilized more and more throughout the United States and in nations around the world. It is helpful to realize the history in regards to passive solar energy, and the benefits that can be gained by applying passive solar energy.

Overall, the various types of passive solar energy have unique strengths and weaknesses. Direct gain, the simplest application of passive solar energy, provides quick, economically friendly, inexpensive heating for a home. The main disadvantage is its difficulty in providing adequate control of the environment. Indirect gain, a slightly more complicated use of passive solar energy, goes beyond direct gain and offers a more stable environment with better heat control. However, indirect gain requires greater planning and also takes longer to heat up a room or home. The third application, isolated gain, delivers even more control and stability in controlling the indoor environment. This, too, requires further planning and is more expensive to construct.

The five strategies used for passive solar energy, direct gain, thermal storage, solar greenhouses, roof ponds, and convection loops, all have their own advantages and disadvantages as well. The main drawback to implementing these strategies into a building is a need for further planning and specific materials. However, this increased initial cost only increases the long-term savings for a building using passive solar energy. The use of these approaches to passive solar energy requires an evaluation for each building in regards to feasibility and usefulness. They can certainly be useful in many applications, and are worth considering in the planning process.

Passive solar energy will continue to grow and change, providing inexpensive, sustainable alternatives for common heating and cooling systems. As technology improves and awareness increases, passive solar energy will become more widely used throughout the country and around the world. It is certainly a viable option for new construction, and will continue to assist in saving energy for many.