Green Field: Passive Solar Architecture

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Abstract–Passive cooling systems were tested to discover the most efficient way to cool a building using minimal energy. In order to perform this experiment, the temperature and relative humidity of each system was recorded. The systems were modeled by Styrofoam coolers and tested over a period of about twenty-four hours. The results showed that the Light Shelf, Awnings and Earth Shading systems worked the best in keeping the conditions of the model rooms closest to the ideal comfort zone. Surprisingly, the box that was painted black on the inside had the best results, which implies that materials with a high ability to retain heat are most effective in lowering temperature and humidity.

Keywords: Passive Solar, Green Homes

I. INTRODUCTION

In order to run all the technology present in the modern world, energy and natural resources are being depleted. Due to high demand, natural gas and electricity are becoming increasingly expensive, causing people to look for ways to perform the same tasks without energy-wasting technology.

Since half of the energy used in an average home is used to heat or cool rooms, using solar energy to control the temperature is extremely economical. There are many ways of controlling solar gain to minimize the amount of mechanical and electrical heating or cooling. Some of these methods are inherent in the architectural elements of the building, which can be designed to minimize the building's solar gain. A precedent for a building with no mechanical cooling system is the San Fransisco Federal Building in California. This design incorporates numerous passive cooling strategies that work together to enable the building to remain at a comfortable temperature. There are many different ways to harness solar energy to heat or cool a building. However, they are difficult to combined logically, so a choice must be made between which systems are most efficient. To discover which of these methods are most effective at keeping the indoor atmosphere comfortable, we tested various passive cooling systems to measure temperature and relative humidity and compared them to each other. Each system was modeled by a Styrofoam box representing a simplified version of a house with only one room. From the results, we converted the temperature to kilowatt-hours in order to determine which system is the most efficient in terms of time and cost. We also tested a solar panel to predict the characteristics needed to cool an average house, thereby testing its economical capabilities. Then, we used our results and our research to incorporate the most practical cooling methods into a logical proposed design for a house. Ideally, this house stays cool without the use of any mechanical systems.

II. PASSIVE VERSUS ACTIVE COOLING SYSTEMS

2.1 Passive Cooling Systems

Passive Cooling Systems use structural and design elements to minimize the solar gain and therefore keep the indoor atmosphere comfortable. They are implemented by architects to minimize the amount of mechanical cooling (air conditioning, for example) needed to keep the occupants comfortable. Major factors in Passive Cooling are the facades of a building and the sun's azimuth angle and angle of altitude. As the sun progresses across the sky, its light is more direct on some facades than others.

The east and west facades get the most sunlight because the sun travels from east to west and directly faces these facades as it crosses the sky. The south facade gets direct sunlight during the middle of the day while the north facade gets mostly indirect sunlight. In the northern hemisphere, the south facade gets more sunlight than the north because the south faces the equator. The farther the site is away from the horizontal angle from directly overhead, and the azimuth angle, which is the vertical angle of the sun, measured on a north-south line. The angle of altitude is primarily used on the eastern and western facades to determine the angle the sun hits the house while the azimuth angle is used on the northern and southern facades to determine how far the sun strays from a direct path from east to west.

There are a few general ways of using Passive Cooling in a building. The most direct method of

Passive Cooling is blocking the sunlight as much as possible with overhangs, thereby preventing it from heating the room. Another way to lower the solar gain of a building is to use light-reflective materials. Since they absorb less sunlight, they absorb less heat and the building remains cooler. Using building materials with a high thermal mass, such as concrete, can also be beneficial because they absorb heat and store it for a long period of time, releasing it later.

Light Shelves are reflective overhangs that are most effective on the east and west facades, where they can block the most direct sunlight. Light

Shelves not only reflect the natural light deeper into the room, but they also provide shade. The azimuth angle is used to determine how far the overhang must reach outside of the structure to block the most amount of sunlight from reaching the room. Ideally, a white reflective metal should be used for the Light Shelves because it both reflects the natural light into the room and absorbs the least amount of solar heat. In addition, the Light Shelf shouldn't be directly connected to the window. There should be a space for cool air to pass through and prevent hot air from being trapped beside the window.

Awnings, which are overhangs made of any type of protective cloth, work in a similar fashion. The cloth can be retracted, which allows awnings to be fully adjustable for annual, daily or hourly conditions, so that the length of the overhang can be changed depending on the sun's angle of altitude.

They are best used in the south, east and west facades where they are most functional in blocking the sun.[14]

Vertical Fins are also used to block the sun. However, they are usually placed on the north and south facades, where they can block the indirect sunlight rather than focus on blocking direct sunlight. They are typically positioned perpendicular to the house. In order to make the fins as effective as possible, each fin and the spacing between fins must be dimensioned specifically for each window at a given site to provide the room with as much shade as possible. These dimensions are determined by the azimuth angle. However, at noon, the sun is directly facing the south facade, which makes the fins ineffective. Ideally, the fins should be opaque to block any sunlight from passing through. Just as in the Light Shelves, space between the window and fin can also help cool the room by allowing wind to pass through and cool the area.

A radically different approach to Passive Cooling is the Roof Pond System, which works like a thermal sponge, using insulated panels that remain closed by day to reject unwanted solar heat during the summer. This system also absorbs room heat conducted through the interior ceiling. During the night, the panels are rolled back, exposing the pond to cool air as it loses heat by radiation to the night sky. In order to be most effective, the ponds should range from six to twelve inches in depth, depending on location. The system is least effective in regions of high humidity, which cause an increase in the evaporation of water from the ponds. Obstructions such as adjacent trees and buildings can impact the cooling rate because they absorb solar heat by day and radiate energy into ponds at night, which reduces the ponds' effectiveness.

A Green Roof works similarly to the Reflective Exterior by preventing solar heat from reaching the room below. However, the Green Roof accomplishes this by absorbing the heat rather than reflecting the sunlight away. The Green Roof is essentially a roof covered by vegetation planted over a waterproof membrane. To keep the weight load of the roof as low as possible, shallow-rooted plants are usually grown on a Green Roof. The plants and soil reduce the solar gain of the building by absorbing solar heat and preventing it from reaching the room below. The plants both physically shade the roof from sunlight and transpire water vapor to help rid the roof of absorbed heat.

Another type of Passive Cooling is Earth Shading, which allows heat from inside the building to be transferred to the soil rather than remain in the building. It works best in areas where the average annual temperature is below 60F. Ideally, the earth should be covered with white gravel, which reflects the sunlight and keeps the earth even cooler, allowing more heat to pass from the building to the soil.

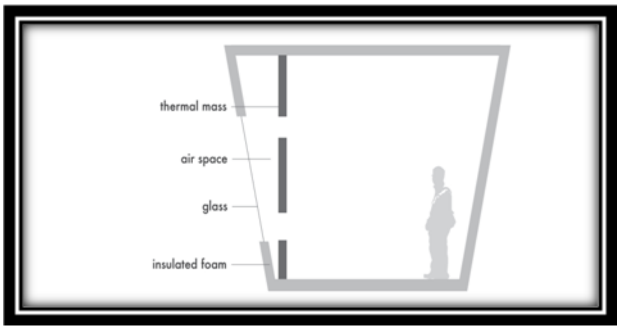

Fig. 1: Trombe Wall

This system is most effective if a majority of the building is in direct contact with the earth. However, burying a house underground sacrifices window space. A possible solution is where the building is half-buried in a sloped section of soil.[1]

Another system is the Trombe Wall, as seen in Figure 1, which absorbs heat from the atmosphere by placing a glass window a few inches in front of a concrete wall. Trombe Walls absorb the solar heat that passes through the window during the day, cooling the air in the room and giving off heat to the house gradually throughout the night. It also absorbs heat from the room, which cools it down.

In order for the Trombe Wall to be most effective, two horizontal openings in the wall are needed to maximize air circulation. Wind blows cold air into the bottom opening. The cold air then rises to the top opening, pushing the hot air through a gap between the concrete wall and the glass window.

The Cool Tower uses air movement to control the temperature of the building. It is a reverse chimney, with cool air flowing down instead of hot air flowing up. Above the roof, a rotating metal scoop follows the wind current, forcing warm air to be pulled into the tower. Inside the tower, water is sprayed on absorbent pads, cooling the warm air which enters the tower. The air becomes denser, sinks, and then enters the building through fireplace-like structures.

Cool Tower can be constructed in with an easily heated black metal absorber on the inside behind a glazed front that can reach high temperatures and be insulated from the house. The chimney must end above the roof level.

The last system is Night Flush Cooling, as seen in Figure 2, in which windows are opened and the cool night air flows into the house. During the day, the windows are closed, trapping the cool air inside and allowing for maximum cooling. The walls and

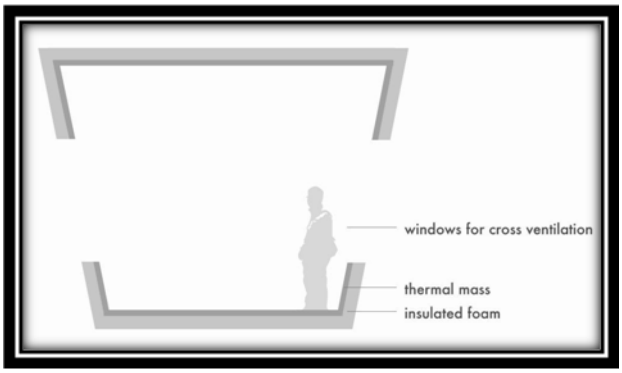

Fig. 2: Night Flush

Cooling floor of the building are composed of concrete to allow for maximum cooling. The concrete absorbs the cool air during the night. This system works best in the summer when the days are hot. During the daytime, the concrete absorbs the hot air from the room, reducing the amount of heat that is left in the air. This system also decreases humidity. Since the windows of the house must be closed during the day, when the air is most humid, less humidity can penetrate into the house.[2]

2.2 Comparing the Systems

To compare the effectiveness of the passive cooling systems at bringing the indoor temperature and humidity closest to comfortable conditions, a psychrometric chart was used. A psychrometric chart shows the relationships between thermal conditions of the environment. It compares the dry- bulb temperature, which is the temperature read on a thermometer, the wet-bulb temperature, which is the temperature we feel, and the relative humidity. Based on the humidity and the dry-bulb temperature, the wet-bulb temperature can be calculated. The psychrometric chart can also illustrate the comfort zone, defined by the conditions that eighty percent of people find comfortable. The passive cooling systems were compared based on how close the conditions inside the systems were to the comfort zone compared to the outdoor conditions.

3 INSTRUMENTED COOLING SYSTEMS

In order to determine the effectiveness of each passive cooling system, we modeled each in an insulated container, a Styrofoam cooler. Then we tested the conditions in each of the containers and recorded temperature and relative humidity. All the containers are the same dimension: 13 inches high with the top side 17 by 12 inches and the bottom side 12 by 7 inches. Each model was also constructed with a single 8 by 6 inch window, unless a different window configuration was critical to the system tested. The roofs of the boxes were made out of the tops of the Styrofoam coolers, secured with white duct tape to reflect the most sunlight.

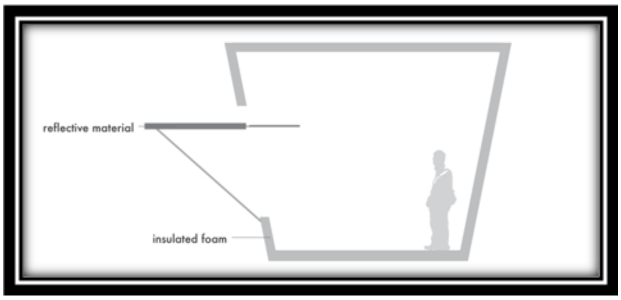

Fig. 3: Light Shelf

Testing was done over the course of two days. Each system was tested for twenty-four hours, with data taken every one to two hours, with the exception of the roof pond system, which needed a forty-eight hour cycle to be tested completely. The control is a Styrofoam cooler with one 8x6 in window. This is the standard to which we compare all other systems. The first experimental box was painted black on the inside to test how the interior wall color affected temperature through solar gain. The black interior should absorb more of the sunlight shining through the window than a white interior.

For the model of the Light Shelf, as seen in Figure 3, an overhang was properly dimensioned to be 10 by 7 based on the angle of altitude at the site. The overhang was made out of poster board

covered in aluminum foil. The aluminum reflected some of the sunlight further into the room but it also reflected some of it out of the system. The overhang was placed an inch below the top of the window so sunlight would be let into the box but the overhang could still block a majority of it from the solar heat. A cloth shelf made out of white fabric and Popsicle sticks was placed on the inside of the box, as shown in Figure 13. The cloth shelf still let some light through but reduced glare, making the room more comfortable for its occupants. (Figure 13 - diagram). The Light Shelf model was placed facing the west facade, where it could block the most direct sunlight.

The model of the Awning, as seen in Figure 4, was made out of foam board and white cloth. The framework, a rectangle measuring 10 by 7 inches, was made out of foam board and covered with white cloth that reflected the heat radiating from the sun.

The Awning was placed perpendicular to the building to block the most amount of sunlight. The Awning model was tested facing the west facade so that the overhang could block the most direct sunlight.

The Vertical Fins, as seen in Figure, were made out of quarter-inch-thick foam board. The fins were dimensioned and spaced out based on the azimuth angle to be one inch wide and one inch spaced out,

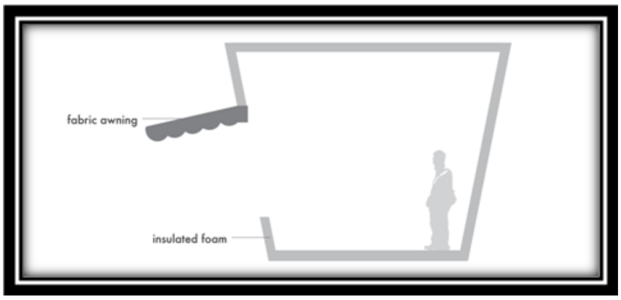

Fig. 4: Awning

with each fin extending over the entire height of the window. These dimensions were specific to the width of the fin, since wider fins would allow for wider gaps between. However, using shorter fins was more practical and similar to the proportions of a real building with vertical fins.

There were eight fins in total, covering the entire window, as seen in Figure 3.

The Roof Pond, as seen in Figure 6, system was built out of foam board and water. The foam board was the interior roof, fitted on the top of the box but pushed down below the edges to prevent the "bladder" of water from falling off. The "bladder" was made out of a black trash bag filled with water. The "bladder" was then covered with a Sty-rofoam cover during the day to prevent the water from evaporating.

For the Reflective Exterior model, as seen in Figure 7, seen in Figure 5, the Styrofoam box lid was turned upside down so that the roof was convex rather than concave so that there was more roof surface for the sun to reflect off of. The roof was covered with aluminum foil representing the reflective properties. The roof was fastened on through the use of white duct tape. The window opening is facing the east facade.

The Green Roof, as seen in Figure 7, was modeled as the blue star creeper planted in the Sty-rofoam cover of the box, covering most of the lid as shown in Figure 6. The blue star creeper was chosen because it is a shallow-rooted, low-growing plant that could easily model vegetation on top of a real Green Roof. The blue star creeper was watered and exposed to sunlight prior to testing the model to keep it alive.

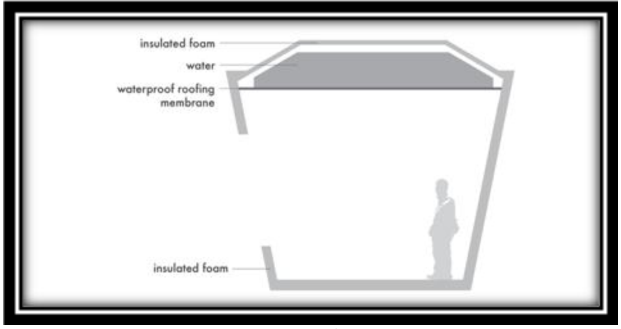

Fig. 5: Roof Pond

For the Earth Shading System, as seen in Figure 7, the Styrofoam box was half-buried in soil in a plastic container.

The earth was modeled in layers, as seen in Figure 7. The first layer was large, round stones to provide a base for the soil. The next layer was soil dug up from the site. The final layer was white gravel that could reflect the most amount of sunlight. The window side of the box was left unburied and the part of the plastic container that blocked the window was cut away.

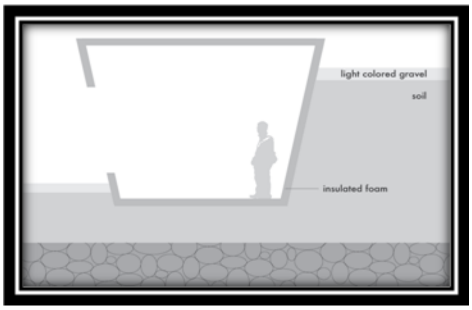

Fig. 6: Earth Shading

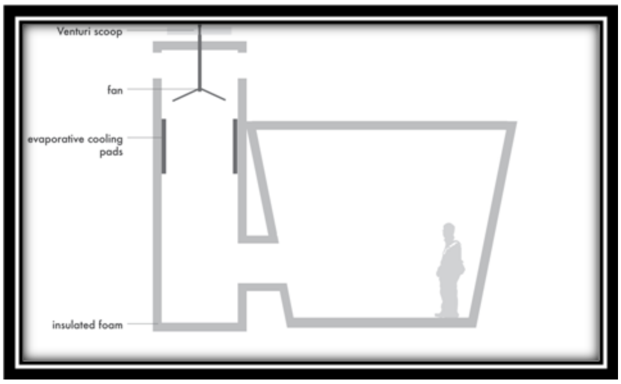

Fig. 7: Cool Tower

The pencil was stuck through the center of the roof. A fan, made out of three teardrop shaped cardboard pieces covered with duct tape, was attached to the tip of the pencil inside the tower. The duct tape ensured that the system remains waterproof. The rotating system allowed wind to spin the fan inside the tower by spinning the one above it, as seen in Figure 7. Beneath the fan, four sponges acting as absorbent pads line the inside of the Cool Tower. The sponges were watered by hand every hour so that they could cool the warm air. Finally, the model Cool Tower was attached to the Styrofoam box by a foam board tunnel acting as the fireplace.

III. RESULTS AND DISCUSSION

4.1 Effectiveness of System Tested

Out of the systems tested on Day One, the Light Shelf was the most effective in lowering temperature but the Awning was most effective in lowering humidity. To determine which system was most effective in keeping a comfortable atmosphere, the averages of the temperature and humidity between 10:00 and 3:00 were plotted on a psychometric chart, which indicates the comfort zone based on dry-bulb temperature and humidity. The black box was closest to the comfort zone, followed closely by the Light Shelves and the Awnings.

4.2 Errors

As can be expected, the model systems did not perform to their full potential because of insufficient resources. On the first day of testing, it was extremely windy, causing several boxes to be knocked over. Consequently, we had to weigh them down with rocks, which increased the thermal mass.

Also, when opening and closing the lids on the boxes to collect the data, the lids were not always taped down equally tightly. Because Styrofoam is a higher thermal mass than normal building insulation, the boxes absorbed more heat than they would in a realistic situation.

IV. CONCLUSIONS

The project helps discover which passive cooling system would be most effective in a building. From the data, it was determined that the Light Shelf, Awning, Earth Shading and black box were the most effective. The experiment on passive cooling systems has demonstrated the possibilities of future architecture. If passive cooling systems were proven to be efficient enough to cool an entire building, it could lead to an end to the world's energy crisis.

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