Analysis of Passive Solar Energy Building With Rainwater Harvesting System

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I. INTRODUCTION

Passive solar heating is one of several design approaches collectively called passive solar design. When combined properly, these strategies can contribute to the heating, cooling, and day lighting of nearly any building. The types of buildings that benefit from the application of passive solar heating range from barracks to large maintenance facilities.

Typically, passive solar heating involves:

- The collection of solar energy through properly- oriented, south-facing windows.
- The storage of this energy in "thermal mass," comprised of building materials with high heat capacity such as concrete slabs, brick walls, or tile floors.
- The natural distribution of the stored solar energy back to the living space, when required, through the mechanisms of natural convection and radiation.
- Window specifications to allow higher solar heat gain coefficient in south glazing.

II. LITERATURE SURVEY

The solar energy that falls naturally on a building can be used to heat the building without special devices to capture or collect sunlight in direct gain passive solar system. Passive solar heating makes use of large sun- facing windows (south-facing in the Northern Hemisphere) and building materials. A well-insulated building with such construction features can trap the sun‟s energy and reduce heating bills as much as 50 percent. Passive solar designs also include natural ventilation for cooling. Shading and window overhangs also reduce summer heat while permitting winter sun. In this paper, the heat energy obtained from solar energy is stored by thermal mass floor which is used to maintain comfortable higher temperature inside the room in day time as well as in the night. The thermal mass floor was made of stone chips. The overhang was also designed in simple, new, and effective way to reduce over heating during summer. The low cost materials used for the study in order to focus on low cost construction with comfortable result. This thesis investigates the potentials of the use of Passive Solar Design strategies in existing low-rise residential buildings in the context of energy-efficient building design. Among the ways of developing energy-efficient building design, there are mainly active and passive systems to consider and the thesis focuses on passive ones which require integration of architectural characteristics and energy-efficiency strategies, which can likely be cost-effective and thermally comfortable as a result of that integration.

II. MATERIALS AND METHODS

Two primary elements of passive solar heating are required:

- South facing glass
- Thermal mass to absorb, store, and distribute heat

There are three approaches to passive systems – direct gain, indirect gain, and isolated gain. The goal of all passive solar heating systems is to capture the sun‟s heat within the building‟s elements and release that heat during periods when the sun is not shining. At the same time that the building‟s elements (or materials) is absorbing heat for later use, solar heat is available for keeping the space comfortable (not overheated).

DIRECT GAIN

In this system, the actual living space is a solar collector, heat absorber and distribution system. South facing glass admits solar energy into the house where it strikes directly and indirectly thermal mass materials in the house such as masonry floors and walls. The direct gain system will utilize 60 – 75% of the sun‟s energy striking the windows.
In a direct gain system, the thermal mass floors and walls are functional parts of the house. It is also possible to use water containers inside the house to store heat. However, it is more difficult to integrate water storage containers in the design of the house. The thermal mass will temper the intensity of the heat during the day by absorbing the heat. At night, the thermal mass radiates heat into the living space.

2.1.1 Direct gain system rules of thumb:

- A heat load analysis of the house should be conducted.
- Do not exceed 6 inches of thickness in thermal mass materials.
- Do not cover thermal mass floors with wall to wall carpeting; keep as bare as functionally and aesthetically possible.
- Use a medium dark color for masonry floors; use light colors for other lightweight walls; thermal mass walls can be any color.
- For every square foot of south glass, use 150 pounds of masonry or 4 gallons of water for thermal mass.
- Fill the cavities of any concrete block used as thermal storage with concrete or other high mass substance.
- Use thermal mass at less thickness throughout the living space rather than a concentrated area of thicker mass.
- The surface area of mass exposed to direct sunlight should be 9 times the area of the glazing.
- Sun tempering is the use of direct gain without added thermal mass. For most homes, multiply the house square footage by 0.08 to determine the amount of south facing glass for sun tempering.

INDIRECT GAIN

In an indirect gain system, thermal mass is located between the sun and the living space. The thermal mass absorbs the sunlight that strikes it and transfers it to the living space by conduction. The indirect gain system will utilize 30 – 45% of the sun‟s energy striking the glass adjoining the thermal mass. There are two types of indirect gain systems:

- Thermal storage wall systems (Trombe Walls)
- Roof pond systems

Thermal storage wall systems:

The thermal mass is located immediately behind south facing glass in this system Operable vents at the top and bottom of a thermal storage wall permit heat to convict from between the wall and the glass into the living space. When the vents are closed at night radiant heat from the wall heats the living space.

Roof pond systems

Six to twelve inches of water are contained on a flat roof. This system is best for cooling in low humidity climates but can be modified to work in high humidity climates. Water is usually stored in large plastic or fiberglass containers covered by glazing and the space below is warmed by radiant heat from the warm water above. These require somewhat elaborate drainage systems, movable insulation to cover and uncover the water at appropriate times, and a structural system to support up to 65 lbs/sq.ft dead load.

Indirect gain system rules of thumb for thermal storage walls.

The exterior of the mass wall (toward the sun) should be a dark color. Use a minimum space of 4 inches between the thermal mass wall and the glass. Vents used in a thermal mass wall must be closed at night. A well-insulated home will require approximately 0.20 square feet of thermal mass wall per square foot of floor area or 0.15 square foot of water wall. If movable night insulation will be used in the thermal wall system, reduce the thermal mass wall area by 15%.Thermal wall thickness should be approximately 10-14 inches for brick, 12- 18 inches for concrete, 8- 12 inches for adobe or other earth material and at least 6 inches for water.

ISOLATED GAIN

An isolated gain system has its integral parts separate from the main living area of a house. Examples are a sunroom and a convective loop through an air collector to a storage system in the house. The ability to isolate the system from the primary living areas is the point of distinction for this type of system.

The isolated gain system will utilize 15 – 30% of the sunlight striking the glazing toward heating the adjoining living areas. Solar energy is also retained in the sunroom itself. Sunrooms (or solar greenhouses) employ a combination of direct gain and indirect gain system features. Sunlight entering the sunroom is retained in the thermal mass and air of the room. Sunlight is brought into the house by means of conduction through a shared mass wall in the rear of the sunroom, or by vents that permit the air between the sunroom and living space to be exchanged by convection.

The use of a south facing air collector to naturally convict air into a storage area is a variation on the active solar system air collector. These are passive collectors. Convective air collectors are located lower than the storage area so that the heated air generated in the collector naturally rises into the storage area and is replaced by return air from the lower cooler section of the storage area. Heat can be released from the storage area either by opening vents that access the storage by mechanical means (fans), or by conduction if the storage is built into the house.

The sunroom has some advantages as an isolated gain approach in that it can provide additional usable space to the house and plants can be grown in it quite effectively. The convective air collector by comparison becomes more complex in trying to achieve additional functions from the system. This is a drawback in this area where space heating is less of a concern than in colder regions where the system would be used longer. It is best to use a system that provides more than one function if the system is not an integral part of the building. The sunroom approach will be emphasized in this information since it can provide multiple functions.

Sunrooms:

Sunrooms can feature sloped and/or overhead glass, but is not recommended for the Austin area. A sunroom will function adequately without overhead or sloped glazing. Due to long hot summers in this area, it is important to use adequate ventilation to let the heat out. Sloped or overhead glazing is also a maintenance concern. Due to the intensity of weather conditions for glazing facing the full ventilation: passive design and brunt of the sun and rain, seals between the gazing panels need to be of extremely high material and installation quality.

A thermal wall on the back of the sunroom against the living space will function like the indirect gain thermal mass wall. With a thermal wall in the sunroom, the extra heat during the day can be brought into the living space via high and low vents like in the indirect gain thermal wall. More elaborate uses of the heated air generated in the sunspace can be designed into this system, such as transferring the hot air into thermal mass located in another part of the house.

Isolated Gain rules of thumb for sunrooms:

Use a dark color for the thermal wall in a sunspace. The thickness of the thermal wall should be 8-12 inches for adobe or earth materials, 10-14 inches for brick, 12-18 inches for (dense) concrete. Withdraw excess heat in the sunroom (if not used for warm weather plants) until the room reaches 45 degrees and put the excess heat into thermal mass materials in other parts of the house.

For a sunroom with a masonry thermal wall, use 0.30 square feet of south glazing for each square foot of living space floor area. If a water wall is used between the sunroom and living space instead of masonry, use 0.20 square feet of south facing glass for each square foot of living area. Have a ventilation system for summer months .If overhead glass is used in a sunroom, use heat reflecting glass and or shading systems in the overhead areas.

PASSIVE SOLAR COOLING

Normally, buildings are conditioned to supply a comfortable environment for the occupants. This process involves heating, cooling, humidifying, dehumidifying or ventilation. Cooling is an important element from the point of energy economy in developed countries, with air conditioning causing peaks in electricity use on summer days. If passive cooling and passive solar technologies can be utilized to cool the buildings, it will decrease the demand of electricity use for the cooling of buildings. Beyond this, with a combination of solar heating and passive cooling will be in most places more economical than heating or cooling alone. There are four types of passive cooling for the buildings: Ventilative, Radiative, Evaporative, and Mass effective cooling methods. Passive cooling techniques can be used to reduce, and in some cases eliminate, mechanical air conditioning requirements in areas where cooling is a dominant problem.

Ventilative Cooling

The main concept of ventilative cooling is to carry heat away from the building and human body by using air. Air movement may be induced either by natural forces or mechanical power. But in passive systems, the considerations of thermal comfort should be integrated into the building‟s fabric and its architectural design without relying on any mechanical devices. The European Passive Solar Handbook (1992)points out that natural ventilation can produce a significant cooling effect, depending on the configuration of the building on the site and the surrounding spaces and according to it, the layout of internal spaces in plan and section according to function is important for air movement and the potential for cross ventilation. The distribution of openings on the building facade (fenestration) is a key issue for efficient natural ventilation. Air flow patterns are the result of differences in the pressure distribution around and within the building. Ventilating a building provides air exchange between the inside and outside; this overall ventilative replacement of warmer inside air with cooler outside air is the source of building cooling.

A primary strategy for cooling buildings without mechanical assistance (passive cooling) in hot humid climates is to employ natural ventilation. (The Fan and Landscape sections also address ventilation strategies.) In the Austin area, prevailing summer breezes are from the south and southeast. This matches nicely with the increased glazing on the south side needed for passive heating, making it possible to achieve helpful solar gain and ventilation with the following strategies:

- Place operable windows on the south exposure.

- Casement windows offer the best airflow. Awning (or hopper) windows should be fully opened or air will be directed to ceiling. Awning windows offer the best rain protection and perform better than double hung windows.
- If a room can have windows on only one side, use two widely spaced windows instead of one window.

Wing Walls

Wing walls are vertical solid panels placed alongside of windows perpendicular to the wall on the windward side of the house. Wing walls will accelerate the natural wind speed due to pressure differences created by the wing wall.

Thermal Chimney

A thermal chimney employs convective currents to draw air out of a building. By creating a warm or hot zone with an exterior exhaust outlet, air can be drawn into the house ventilating the structure. Sunrooms can be designed to perform this function. The excessive heat generated in a south facing sunroom during the summer can be vented at the top. With the connecting lower vents to the living space open along with windows on the north side, air is drawn through the living space to be exhausted through the sunroom upper vents. (The upper vents from the sunroom to the living space and any side operable windows must be closed and the thermal mass wall in the sunroom must be shaded.)

Thermal mass indirect gain walls can be made to function similarly except that the mass wall should be insulated on the inside when performing this function. Thermal chimneys can be constructed in a narrow configuration (like a chimney) 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 terminate above the roof level. A rotating metal scoop at the top which opens opposite the wind will allow heated air to exhaust without being overcome by the prevailing wind. Thermal chimney effects can be integrated into the house with open stairwells and atria.

Shading

An important element of solar design for summer climates is reducing the amount of solar gains through windows and walls in the summer months. The most effective and affordable way to achieve this is through shading devices. Entire walls can have shading devices to reduce the outer surface temperature of the wall. Figure 3 shows four types of wall shading devices: a) vegetation, b) wooden or metal louvers, c) vegetation on steel or Hardwood mesh, d) a second skin with a low-emission layer on the inner surface and a heat-reflective outer surface.

More important than wall shading is window shading. Since windows are transparent they allow solar radiation into the living space. The primary goal of window shades is to completely block out any direct solar radiation on the window, reducing the possibility of heat gain. The orientation of shades depends on which face of the building they are on. Shades on the south and north faces of a building should be horizontal since the sun will generally have a high elevation when striking these surfaces. Shades on the east and west sides of a building should be vertically oriented since the sun will usually beat lower angles when striking these surfaces.

No matter what type of shading device is used, there are several goals that the design should accomplish:

- Shades should be on the outside of the opening.
- Shades should be made of light and reflective materials to avoid absorption and re-radiation.
- Materials should have low heat storage capacity for rapid cooling.
- The design should prevent reflection onto any part of the building or openings.
- Hot air should not be trapped against the building.

RADIATIVE COOLING:

Radioactive cooling is the transfer of heat from a warmer surface to a cooler surrounding surface. Any object emits energy by electromagnetic radiation. If two elements at different temperatures are facing one another, a net radiant heat loss from the hotter element will occur. And if the coldest element is kept at a fixed temperature, the other element will cool down to reach equilibrium with the colder element. This physical principle forms the basis of radiative cooling.

EVAPORATIVE COOLING: Evaporation occurs whenever the vapour pressure of water is higher than the partial pressure of the water vapour in the adjacent atmosphere. The phase change of water from liquid to vapour is accompanied by the release of a large quantity of sensible heat from the air that lowers the dry bulb temperature of the air while moisture content of the air is increased. The efficiency of the evaporative cooling process depends on the temperatures of the air and water, the vapour content of the air and the rate of airflow past the water surface.

Direct Evaporation:

The system that the moisture content of the cooled air is increased causing augmentation of relative humidity in the atmosphere. Direct evaporation system occurs when dry air is blown over a wetted surface. Many examples of this system exist in vernacular architecture. Their main disadvantage is in the increased moisture content in the ventilation air supplied to the indoor spaces.

Indirect Evaporation:

Indirect evaporative systems avoid the problems associated with increased humidity levels. In this system, the evaporatively cooled air is separated from the conditioned room air allowing reducing the dry-bulb temperature without adding humidity to the room air. Exterior building wall and roof surfaces heated by radiation or convection may be cooled by spraying them with water. As the water evaporates it cools the surface. It is sufficient to keep the surfaces moist.

THERMAL MASS

In both direct- and indirect-gain cases, it is important to store the incoming solar energy. Thermal mass is any material that stores energy from the sun. While all materials will absorb and store a certain amount of energy, some are better suited to the task than others. Generally, materials that are denser tend to store more energy than less dense materials. The measure of possible storage for thermal mass is the volumetric heat capacity (VHC). The VHC is determined by multiplying the density (ρ) by the specific heat (cp) of the material. The VHC is a measure of how much heat is stored for a rise of1°F for one cubic foot of material. A high VHC is desired for thermal mass. Another important property of thermal mass is the thermal conductivity (k) which is the measure of how quickly energy transfers linearly through a material for 1°F of temperature difference. The higher the conductivity of the thermal mass the faster the material will gain or lose heat.

Following table shows the thermal properties of common construction materials used as thermal mass

III. RESULT DISCUSSION

Summer Season

Summer day time total sunny days are 10 to 12 hours. The solar panel with 12v output with 1000w.

Therefore the power generated will be 1000W x 10 hrs = 10 kWhr = 10 units Saving in rupees per day
10 units x Rs. 8.5⁄unit = Rs. 85

As we have design the building as a passive solar energy building so no need of tube lights during day time i.e. average 10 to 12 hours. So 2 tubes in hall and 1 tube in kitchen and 1 tube in bedroom total 4 tubes of 28w

Saving of electricity per day

= 28 x 4 = 112 watts per hour x 10 to 12
= 1120 to 1344 watts per day..

Winter Season

Winter day time total sunny days are 08 hours. The solar panel with 12v output with 1000w. Therefore the power generated will be1000W x 08 hrs = 08 kWhr = 8 units Saving in rupees per day08 units x Rs. 8.5⁄unit = Rs. 68

As we have design the building as a passive solar energy building so no need of tube lights during day time i.e. average 08 hours. So 2 tubes in hall and 1 tube in kitchen and 1 tube in bedroom total 4 tubes of 28w

Saving of electricity per day
= 28 x 4 = 112 watts per hour x 08 hours
= 896 watts per day. Saving in rupees per day
0.896 units x Rs. 8.5⁄unit = Rs. 7.615

In winter heater is not needed as the thermal wall is developed which will store the heat in daytime so running the heater cost will be saved.

Three heater of wattage 2000 Watts are used averagely for 4 to 05hrs per day. So the saving of electricity per day will be = 2000 Watts x 4 to 5 hrs x 3 nos = 24 to 30 kWhr Saving in rupees per day24 to 30 units x Rs. 8.5⁄unit = Rs. 204 to 255

Energy production can be increased by increasing solar panels. As our building has natural lights and ventilation there is minimum use of electricity, so if in case our energy production is less or minimum this will not cause any serious issue.

If our production of energy is in higher amount, it can be sell to MSEB by rate metering at Rs.4.65/unit. Thus it is one of source of earning money

Rain water harvesting

The average rainfall at Faizpur is 22 inch to 25 inch. We design a building whose roof area is 1000 sq. feet. Then in a rainy season, the total water collected will be = 1000 x (22 to 25) 12 = 1833 to 2083 cu ft = 52002 to 59094 lits

which will be sent to the water tank placed at the ground for regular utility or excessive water will be sent to the bore well as well as this water can be sent to the municipal water treatment plant for purify the water. If it is applied for society i.e. amount of water collected from houses in society stored in storage tank. Then it will send to municipal storage where treatment on this collected water will be done. This will lead to saving of water at great extent.

Do's and Don'ts

Harvested rainwater is used for direct usage or for recharging aquifers. It is most important to ensure that the rainwater caught is free from pollutants. Following precautionary measures should be taken while harvesting rainwater:-

- Roof or terraces uses for harvesting should be clean, free from dust, algal plants etc.
- Roof should not be painted since most paints contain toxic substances and may peel off.
- Do not store chemicals, rusting iron, manure or detergent on the roof.
- Nesting of birds on the roof should be prevented.
- Terraces should not be used for toilets either by human beings or by pets.
- Provide gratings at mouth of each drainpipe on terraces to trap leaves debris and floating materials.
- Provision of first rain separator should be made to flush off first rains.
- Do not use polluted water to recharge ground water.
- Ground water should only be recharged by rainwater.
- Before recharging, suitable arrangements of filtering should be provided.
- Filter media should be cleaned before every monsoon season.
- During rainy season, the whole system (roof catchment, pipes, screens, first flush, filters and tanks) should be checked before and after each rain and preferably cleaned after every dry period exceeding a month.

IV. CONCLUSION

1. By using solar panels, thermal mass we have make the building economical.
2. We have reduced the energy required for building by providing the natural light, ventilation to the building.
3. Home systems can be relatively simple to install and operate may reduce water bill with the use of rainwater harvesting.
4. Maximum use of nonrenewable energy source such as solar energy, wind etc.
5. Excess energy produced or saved will be sell to MSEB.
6. Rainwater harvesting will be applied to society and total water collected will be sent to municipal storage for filtration purpose then provided to society for use.
7. As per requirement of living standard energy production can be increased by increasing the solar panels.
8. It will be the source of money by selling electricity to government

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