2012 International Conference on Clean and Green Energy
IPCBEE vol.27 (2012) © (2012) IACSIT Press, Singapore

A Survey of Energy-Efficient Passive Solar Houses

Alireza Daneshvar Tarigh[1+], Fatemeh Daneshvar Tarigh[2] and Abolfath Nikranjbar[1]

[1] Department of Mechanical Engineering, Karaj Branch, Islamic Azad University, Karaj, Iran

[2] Department of Architectural Engineering, Qazvin Branch, Islamic Azad University, Qazvin, Iran

Abstract. Energy saving is one of the most important issues of this century. Among its different aspects, passive solar house is an attractive one which has been addressed in this paper. Presenting an overview of characteristics and the key features of passive solar houses, we described a range of methods to implement them, including Direct Gain, Indirect Gain (Thermal Storage Wall), Sunspace and Solar Air Collector. Each type is described in depth and compared against each other to capture their uniqueness. Elaborating climate considerations, we explained the common elements of passive solar systems and guidelines for passive solar designs.

Keywords: passive solar house, energy efficient house, passive solar design.

1. Introduction

Global energy demand is set to increase drastically during the 21st century due to change of lifestyles in line with continuously growing industrial needs, all over the world. Today's most consumed energy is taken from fossil fuels such as oil, coal, and gas. But there are a couple of issues arisen with this. The foremost one is that the resources are rapidly getting decreased while a significant part of living and production plants' cost is allocated by energy in industrial and developing societies. Therefore, shifting to clean, renewable sources of energies such as solar, wind energy enabling to cope with the aforementioned problems is inevitable. Solar energy regarded as the most sustainable energy, could play a significant role in solar and passive solar energy utilizations in building, gained through the parts such as walls, floors, windows, exterior building elements and landscaping to control heat generated by sun. Solar heating designs try to trap and store thermal energy from sunlight directly. Using three basic heat transfer mechanisms exclusively incorporated into the architectural design of the building, we provide reduction in heating and cooling loads and comfort in every season.

The rest of the paper is organized as follows: Section 2 describes the Characteristics of passive solar houses, Section 3 elaborates climate considerations, section 4 explains guidelines for passive solar design and finally the paper is concluded in section 5.

2. Characteristics of Passive Solar Houses

Depending to the location and weather, passive solar houses range from those heated almost entirely by the sun to those with south-facing windows that provide some fraction of the heating load. For instance the one which is located at a very cold area near the North or South Pole could not be heated completely by the sun. The difference between a passive solar house and a conventional house is design. The key is designing a passive solar house to best take advantage of local climate. [1]

As a fundamental law, heat moves from warmer materials to cooler ones until there is no longer a temperature difference between the two. To distribute heat throughout the living space, a passive solar house

+ Corresponding author. Tel.: + 989125502522.
E-mail address: alireza.dan@gmail.com.

design makes use of this law through heat-movement and heat-storage mechanisms: conduction, convection and radiation. [1]

Generally the opaque objects absorb 40%–95% of incoming solar radiation from the sun, depending on their color—darker colors typically absorb a greater percentage than lighter colors. This is why solar-absorber surfaces tend to be dark colored. Bright-white materials or objects reflect 80%–98% of incoming solar energy. Clear glass transmits 80%–90% of solar radiation, absorbing or reflecting only 10%–20%. After solar radiation is transmitted through the glass and absorbed by the house, it is radiated again from the interior surfaces as infrared radiation. Although glass allows solar radiation to pass through, it absorbs the infrared radiation. The glass then radiates part of that heat back to the house's interior. In this way, glass traps solar heat entering the house. [1]

A cardinal rule in passive solar design is to set one's sights properly—do not expect more than the sun can deliver. Robert L. Fehr et al [2] believe that many well-designed passive solar homes provide their owners with low energy bills and year-round comfort, as well as natural daylight and visual connection with the outdoors. However, poorly designed passive solar homes may actually have uncomfortable temperature swings both in summer and in winter. James A. Mathias et al [3] proposed that there is a 50% decrease in total electrical use of the actual passive-solar house compared to the same sized house built to the International Energy Code Council.

2.1. The Key Features of Passive Solar Houses

Key features of passive solar houses are [2]:

- Energy conservation measures—energy efficiency is always the most cost effective way and should be the first step in designing any home, including a passive solar home.
- Glass concentrated on the south—south windows let sunlight into the building in winter and can be shaded in summer. Low-emissivity coatings will reduce heat loss at night and heat gain in summer. Meanwhile it is believed that lower east and west glass areas, reduce summer cooling needs because it prevents unwanted sun from entering the home in the morning and afternoon. [4]
- Window shading—overhangs, blinds, shade screens, curtains, and landscaping shade unwanted sunlight in summer.
- Thermal storage mass—tile-covered slab floors, masonry walls, and water-filled containers store solar heat and save energy all year.
- Ventilation—natural breezes, ceiling fans, whole house fans, and space fans can provide comfort during warmer weather.
- Orientation—Orientation and site selection are critical in passive solar design. The passive solar windows must be installed in a way to maximize solar gain in winter and minimize overheating in summer. [4]

2.2. Types of Passive Solar Designs

There are four common types of passive solar designs as follows: [4]

- Direct Gain: Direct gain system, the most common and simple designs, are houses in which the living areas themselves act as collectors of solar energy by using south-facing windows which allow sunlight directly enter the home (Figure 1). Thermal mass in the form of concrete or masonry walls or floors capture and store the sun's energy.

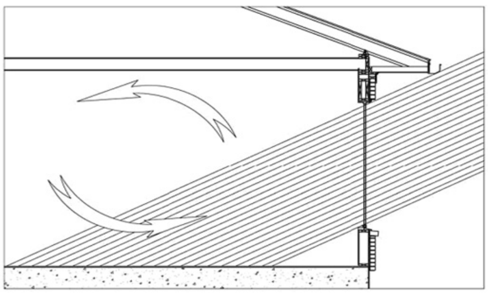

Fig. 1: Direct Gain

- Passive Solar Sunspaces: Sunspaces, rooms independent of the home's heating and cooling system, capture the sun's energy and transfer the heat generated to the house (Figure 2). Sunspaces are also used often but are usually not connected to the central heating and cooling system of the rest of the home. They are comfortable during much of the year, but are not intended as living space year round.

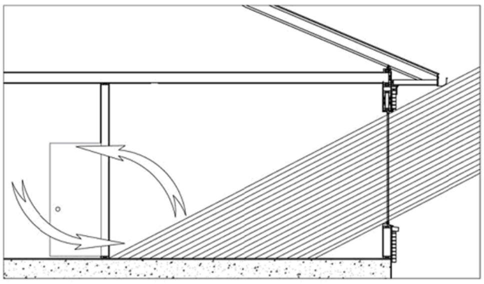

Fig. 2: Passive Solar Sunspace

- Thermal Storage Wall: Thermal storage walls (Figure 3), also known as Trombe wall, require construction of two exterior walls – one made of concrete or concrete-filled block and the other made of glass are more expensive than other passive solar designs. Thermal storage walls store solar heat and let it radiate into the living area. They also do not provide as much savings on heating bills during the cloudy winters.

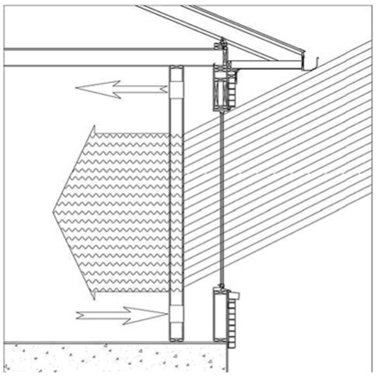

Fig. 3: Thermal Storage Wall

- Solar Air Collector: Solar air collectors absorb incoming solar energy, vent through the back of the air collector, and transfer heated air into the house (Figure 4). They are similar to thermal storage walls but use a conventionally framed wall and function primarily during the day. Eliminating the mass reduces the cost.

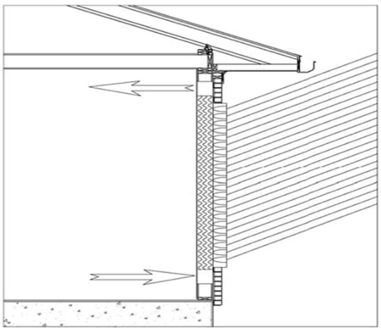

Fig. 4: Solar Air Collector

Andreas K. Athienitis [5] measured the temperature of the south and north of a house located in Montreal which used an ordinary direct gain passive solar system showing that there is a deference of temperature in the south and north part of the house due to the fact that direct gain heats the southern part. It used an auxiliary floor heating system integrated in the floor mass of the direct gain zone with photovoltaic-thermal system and a two-stage ground-source heat pump with ECM (electronically commutated motor) fan used to heat/cool air in the house and achieved a good result to normalize the temperature of the whole building. Feng Jiang et al [6] applied phase change material (PCM) as interior thermal mass and proved by simulation that the passive solar room with the estimated optimal PCM can reach indoor thermal comfort.

Helder Gonçalves et al [7] studied the usage of sunspaces in Portugal and proved that their usage in living spaces is very problematic. When proper solar protection is not used, overheating problems can occur in that type of climate, mainly in summertime. Particular problems in the ventilation of some sunspaces were also found. Ben Cox et al [8] argued that in order to achieve best result with sunspaces, heavy furnishings and rugs must be avoided to prevent shading of the thermal storage mass and shading and venting are important to avoid summertime overheating.

Ben Cox et al [8] criticized the usage of the thermal storage wall or Trombe wall for the following reasons:

- Walls or Floors capture and store the sun's energy.
- South-facing view and natural daylight is almost lost.
- Vented Trombe walls must be closed at night to prevent reverse cycling of heated air.
- The inside of the south-facing glass in a vented Trombe wall will also need to be cleaned from time to time, so access to the glass needs to be considered.
- The Trombe wall may take up too much wall space in a smaller home.
- Furniture and objects placed against or on the Trombe wall affect its efficiency in heating the living space.
- Because the Trombe wall heats only the room it is connected to, the cost of labor and materials in its construction may be high relative to the contribution it makes to the overall heating needs of the house.
- In the summer or on winter days without sunshine, the Trombe wall acts as a very poorly insulated wall. Exterior moveable insulation would improve its effect on comfort and energy use.

Ion V. Ion et al [9] believed that the amount of solar-energy absorbed by a solar energy air heater depends largely on:

- The level of insulation and the solar collector orientation;
- The absorbance of the absorber surface;
- The transmittance of the cover material.

Piotr Matuszewski et al [10] emphasized that solar air collectors has very small heat capacity in comparison with water (air=0.0003 KWh/m^3K ; water=1.16 KWh/m^3K) and a lot of air should be supplied to a building to obtain a higher temperature inside.

2.3. Common Elements of Passive Solar Systems [8]

- Collection – To collect solar energy, double-glazed windows are used on the south-facing side of the house.
- Storage – After the sun's energy has been collected, some heat is immediately used in the living spaces and some is stored for later use. The storage, called thermal mass, is usually built into the floors and/or interior walls. Mass is characterized by its ability to absorb heat, store it, and release it slowly as the temperature inside the house falls. Concrete, stone, brick, and water can be used as mass.
- Distribution – Heat stored in floors and walls is slowly released by radiation, convection and conduction. In a hybrid system, fans, vents, and blowers may be used to distribute the heat.

3. Climate Considerations [11]

The climate of a location is affected by its latitude, terrain, and altitude, as well as nearby water bodies and rivers. But for most climates, we want to maximize solar heat gain in winter and minimize it in summer. We should consider the climate for choosing the best materials such as glazing and so on. Generally climates are classified into the followings:

3.1. Heating-Dominated Climates

In heating-dominated climates, major glazing areas should generally face south to collect solar heat during the winter when the sun is low in the sky. In the summer, when the sun is high overhead, overhangs or other shading devices (e.g., awnings) prevent excessive heat gain. To be effective, south-facing windows usually must have a solar heat gain coefficient (SHGC) of greater than 0.6 to maximize solar heat gain during the winter, a U-factor of 0.35 or less to reduce conductive heat transfer, and a high visible transmittance (VT) for good visible light transfer. Windows on east-, west-, and north-facing walls are reduced in heating climates, while still allowing for adequate daylight. East- and west-facing windows are limited because it is difficult to effectively control the heat and penetrating rays of the sun when it is low in the sky. These windows should have a low SHGC and/or be shaded. North-facing windows collect little solar heat, so they are used just to provide useful lighting.

3.2. Cooling-Dominated Climates

In these climates, particularly effective strategies include preferential use of north-facing windows and generously shaded south-facing windows. Windows with low SHGCs are more effective at reducing cooling loads. The following types of glazing help reduce solar heat gain, lowering a window's SHGC:

- Low-E
- Tinted
- Reflective
- Spectrally Selective[1]

In warmer regions, east and west windows are hard to shade, should probably have low-solar-gain glazing. In such regions, choosing glazing with an extremely low SHGC- especially for east and west windows - will significantly lower air-conditioning loads. Look for windows with SHGCs that are significantly lower than the Energy Star standard of 0.40.

3.3. Heating and Cooling Climates [12]

In a mixed climate, we probably have to choose different types of glazing for different sides of a house. South-facing windows should probably have high-SHGC glazing, especially if the windows are adequately shaded during the summer. West (and east) -facing windows should probably have low-SHGC glazing. Selecting the best glazing for each side is best done with an energy modeling program.

4. Guidelines for Passive Solar Design and Construction [13]

The home's windows, walls, and floors can be designed to collect, store, and distribute solar energy in the form of heat in the winter and reject solar heat in the summer.

4.1. Adequate Solar Access

The longest wall of the home should face within 15° or minus, of true south to receive maximum winter heat gain and minimum summer heat gain. Within 30° east or west of south, the results are reduced 15 percent from the optimum. Facing solar surfaces to the south is not enough to ensure their performance; It is significant also to make sure that the area to the south is clear of obstructions.

However, Bekkouche et al [10] quote as an indication that preventing the overheating of building requires a reduction in solar gain from incoming solar radiation. However, the answer is not simply to use smaller areas of glazing as there is a need for day lighting and views out, and the appearance of the building has to be considered. In this situation we will require to change the orientation of the building to determine the direction that favors minimizing solar gain. They are calculated by (1):

$$Q_S = 24\sum I_{Sj} S_{Sj} \tag{1}$$

where Q_S is the solar heat gain $[\mathrm{W.h}]$, the sum is over all directions j, I_{sj} is the solar irradiation [W/m^2], S_{sj} is the receiving surface of j orientation [m^2] and is computed by (2):

[1] Spectrally selective coatings filter out 40%–70% of the heat normally transmitted through insulated window glass or glazing, while allowing the full amount of light to be transmitted. Spectrally selective coatings are optically designed to reflect particular wavelengths but remain transparent to others. Such coatings are commonly used to reflect the infrared (heat) portion of the solar spectrum while admitting a higher portion of visible light.

$$S_{Sj} = ASFs \tag{2}$$

S is the solar factor, the ratio of the total solar energy flux entering the premises through the glass to the incident solar energy flux. A is the surface opening [m2].

4.2. South-facing windows and thermal mass

In houses with no internal mass, the maximum allowable area of south-facing glass is 7 percent of the floor area.

4.3. Minimizing East and west windows

During the summer, the east and west sides of the house are exposed to the sun’s rays at a low angle for long periods of the day. Reducing windows on these sides can greatly decrease summer heat gain. Unlike the summer sun, the winter sun is low and stays primarily to the south, so east and west windows receive little solar benefit during cold months. A reduction of east and west windows can significantly reduce winter heat loss through the glass.

4.4. Matching the solar heating system to lifestyles

Consider occupancy patterns when choosing a system. What are the heating, lighting and privacy needs after sunset?

4.5. Size of The Overhangs

Overhang should be designed in a way that provides shade (Figure. 5) well into summer and full sun through the winter. Donald Watson et al [14] believed that size of overhang can approximately be calculated according to (3):

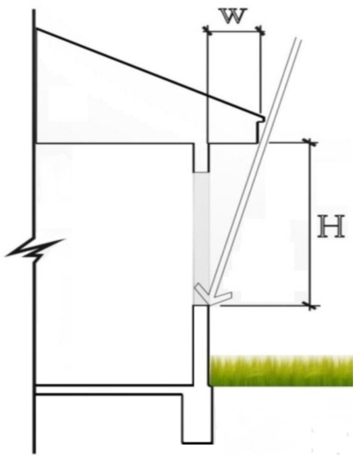

Fig. 5: Overhang in buildings

$$W = \frac{H}{SLF} \tag{3}$$

where W is size of overhang, H is the height from the beneath of the overhang to the bottom of the window and SLF is coefficient which is obtained according to the Table 1:

Table 1. Calculating the size of overhang according to latitude

Window directions	Latitude◦						
	25	30	35	40	45	50	55
East	0.8	0.8	0.8	0.8	0.8	0.8	0.8
South East	1/9	1.6	1.4	1.3	1.1	1.0	0.9
South	10/1	5.4	3.6	2.6	2.0	1.7	1.4
South West	1/9	1.6	1.4	1.3	1.1	1.0	0.8
West	0.8	0.8	0.8	0.8	0.8	0.8	0.8

4.6. Planning the room layout to take advantage of the sun's path

Rooms should match solar gain to the time of day the room is used. It's a good idea to place rooms with low heating, lighting and use requirements on the north side of the building to reduce the effect of winter heat loads. Areas that are not consistently occupied, such as utility rooms, storage rooms, hallways, closets and garages, are good choices. Also, rooms that generate high internal heat gain levels, such as the kitchen or laundry room, work well on the north side. This can reduce the normally higher heat loss through north walls while not interfering with solar access.

4.7. Lightweight materials should be lighter in color

When light energy strikes a surface, it is absorbed and converted into heat energy. If the material does not have sufficient storage mass, the material will release heat it cannot store to the room air, causing overheating. Lighter colors are more reflective so they absorb less energy from sunlight.

4.8. Masonry walls can be any color in direct gain systems

Actually, it is best to use colors in the middle range of the absorptivity scale to diffuse the light energy over the entire storage mass in the room. These colors need to be somewhat darker than the lightweight materials. (The absorption range of natural or colored concrete masonry falls in this range without paints or special treatment being necessary). If the storage mass is too dark in color, there will be high surface temperature at surfaces exposed to the direct rays of the sun while other locations on the same wall may be storing very little of the day's solar energy. Masonry in Trombe walls should always be dark colors to increase absorption. Rugs and wall tapestries also can reduce the effect of storage mass to a great degree. It is wise to plan in advance to match the type of thermal storage to the room's use.

4.9. Distribution of the mass through the room

In direct gain systems, performance is fairly insensitive to the locations of the mass in the room. It is relatively the same whether the mass is located on the floor or on the east, west or north walls. It is important to put some mass in direct sun, but rarely is it possible to expose all the required thermal mass because of furniture and floor coverings. Comfort is improved if the mass is distributed evenly around the room because there is less chance of localized hot or cold spots. Light colored, lightweight materials bounce the sun to more massive materials as long as they are in a room with lots of sun. Also, massive materials in walls that are not in direct sunlight can act as a heat sink, absorbing excess heat from the air and serving to reduce temperature swings.

4.10. Considering night window insulation

Generally R–9 night insulation over double-pane windows provides an approximate 20 percent to 30 percent increase in annual solar performance over systems using double-pane windows without night insulation. Window insulation can be heavy drapes, quilted shades or accordion blinds

5. Conclusion

Energy saving by using solar energy is well-established research area. However, the focus of this paper is to survey passive solar houses, and to point out the unique characteristics and constraints that differentiate passively design building from other types. We present an overview of common types of such houses in several research areas. Discussing many concerns of the types, we elaborate the climate consideration and guidelines for passive solar design. Most of the related literatures show that well-designed passive solar homes provide their owners with low energy bills and year-round comfort, as well as natural daylight and visual connection with the outdoors.

6. References

[1] *Passive Solar Design for the Home.* the Energy Efficiency and Renewable Energy Clearinghouse (EREC), U.S Department of Energy. the National Renewable Energy Laboratory (NREL), 2001.

[2] Robert L. Fehr, *Guide to Building Energy Efficient Homes*, Department of Biosystems and Agricultural Engineering, University of Kentucky, 2009.

[3] James A. Mathias, and Duane M. Mathias, *Energy Efficient, Cost Effective, Passive Solar House*, 2009, pp. 1-9.

[4] *Affordable Passive Solar Planbook,* Appalachian State University Energy Center. Boone, North Carolina: State Energy Office, 2005.

[5] Athienitis K. Andreas, *Design Of A Solar Home With Bipv-Thermal System And Ground Source Heat Pump*, Department of Building, Civil and Environmental Engineering, Concordia University, Montréal, Canada, 2007, pp. 1-8.

[6] Feng Jiang, Xin Wang, and Yinping Zhang, *A new method to estimate optimal phase change material characteristics in a passive solar room*. Energy Conversion and Management. Department of Building Science, Tsinghua University, 2011, pp. 2437-2441.

[7] Helder Gonçalves, Marta Oliveira, Anita Patricio, and Pedro Cabrito, *Passive Solar Buildings in Portugal Experiences in the Last 20 years*. Department of Renewable Energies-INETI.

[8] Ben Cox and Sandra Zaslow, Passive Solar Options For North Carolina Homes. North Carolina Solar Center, Energy Division, N.C. Department of Commerce, 1999, pp. 1-8.

[9] Ion V. Ionn, and Jorge G. Martins, *Design, developing and testing of a solar air collector*. Internal Combustion Engines, Boilers and Turbines, 2006, pp. 1-4.

[10] S.M.A. Bekkouche, T. Benouaz, M.R. Yaiche, M.K. Cherier, M. Hamdani, and F. Chellali, *Introduction to control of solar gain and internal temperatures by thermal insulation, proper orientation and eaves*. *Energy and Buildings Vol. 43*, 2011, pp. 2414-2421.

[11] *U.S. Department of Energy, Energy Efficiency & Renewable Energy*. Retrieved from Energy Savers: http://www.energysavers.gov/your_home/windows_doors_skylights/index.cfm/

[12] *Contemplating residential energy use*. Retrieved from Green Building Advisor: http://www.greenbuildingadvisor.com/book/export/html/18768

[13] *Solar Homes for North Carolina II.* Energy Division, North Carolina Department of Commerce, 1999.

[14] Donald Watson, Kenneth Labs. *Climatic Building Design: Energy-Efficient Building Principles and Practices.* Mcgraw-Hill, 1993.