Comparative Investigation of Traditional, Modern and Designed Solar Passive Building for Thermal comfort in Thanjavur Region

C.V. Subramanian
Department of Architecture
Periyar Maniammai University, Thanjavur, Tamilnadu, India

N. Ramachandran
Periyar Maniammai University, Thanjavur, Tamilnadu, India

S. Senthamil Kumar
Periyar Maniammai University, Thanjavur, Tamilnadu, India

Abstract - Solar Passive Design (SPD) concepts are used in traditional buildings globally. Thermal performance of such traditional buildings is well within the comfort range as prescribed by thermal comfort standards. But in most of the modern buildings, the indoor environmental conditions and thermal comfort are unsatisfactory due to improper design. Hence an attempt is made to design and construct a modern residential building in warm and humid climate of Thanjavur region, Tamilnadu, South India with solar passive architecture concepts and principles that can make the building thermally comfortable like traditional buildings. Solar passive architecture strategies that have been incorporated in the designed building with available modern building materials includes building orientation, courtyard design, light coloured building exterior, heat reflecting roofing tiles, shading elements, solar chimney and sky light, good ventilation, landscaping, roof level ventilators and high ceiling roof. Thermal performance analysis is carried out during summer in the designed building and is compared with a modern house and a traditional house in the nearby region. The study indicates that solar passive techniques can bring indoor temperatures down enough for comfortable indoor environment to the occupants. It is also observed that the indoor temperature of the designed solar passive building is similar to that of traditional building which is 2-3 ºC cooler than the modern building constructed without solar passive design. It is evident from the study that design of building plays a significant role to save energy creating a great impact on economy both at national and global level.

Keywords - Solar Passive Design, Traditional building, thermal comfort, modern building, warm-humid climate

I. INTRODUCTION

Modern buildings designed are frequently seen as the example of Internationalism, producing and enclosing various internal spaces. It eradicates local traditions and transforms the globe into a faceless urban sprawl [1-2]. The modern building design depends more on mechanically controlled environment to maintain comfort of occupants, thereby increasing the energy consumption. Modern designs often are becoming more detached from the limitations imposed by local climate and the environment [3]. Traditional architecture is often neglected which has left the people without the knowledge given by local population on how to create an energy efficient, sustainable and comfortable living environments with limited or no energy consumption. Economic use of the site or construction is the prime focus instead of orientation, design and construction. Building and site are considered in terms of cost and profit. Constructional techniques are replaced by standard components while space standard and guidelines replaced the traditional design knowledge [4].

In the process of modernization and lack of awareness, people are not giving importance to climatic design of buildings. This results in high energy consumption for achieving the required thermal comfort. The traditional building designs at any locality on the other side have evolved through various periods by continuous and consistent effort for efficient solutions [5].

Many investigations have proved that energy savings can be easily achieved in solar passive architecture incorporated traditional houses for maintaining thermal comfort when compared to modern buildings [6-9]. Further efforts have been made worldwide by many researchers to study the passive environmental control methods of achieving thermal comfort in traditional buildings. Also studies for extracting techniques and methods are in progress in various countries like Korea, Zambia, China, Japan, France, Thailand, etc., [10-18]. Providing comfortable indoor environment with energy efficient building designs are also under research area worldwide [19]. Although, the energy conservation building code reports that about 48% of the total energy consumption in Indian residential buildings are utilized for providing indoor thermal comfort [20], studies on various environmental control aspects for thermal comfort in traditional buildings and energy efficiency of buildings have been reported only recently [21-28]. Thermal comfort achieved inside the building by passive methods is the best solution to provide an energy efficient and healthy indoor environment [29-30].

In spite of advantages of traditional buildings over achieving thermal comfort there are certain disadvantages over constructing, maintaining and running such buildings in the present day context. In traditional buildings the area of fenestrations is kept less. Hence the indoor day-lighting conditions are found to be poor in certain areas. Modern buildings provide all necessary hygiene services, lighting and ventilation compared to most traditional buildings. Weathering problems are also caused due to rainfall and also there is a necessity for annual maintenance which makes traditional materials unsuitable for the new towns and cities [4]. Thick external and internal walls, consuming around 35% of plinth area and providing only 65% of the plinth area as carpet area in traditional construction is not acceptable to the occupants of present day context [28]. The owners of most of the traditional houses, though interested to retrofit and rebuild their houses to suit the present day context and continue to benefit from the comfortable conditions instead of moving towards modern construction, find it difficult to replace natural materials with conventional building materials [31-32].

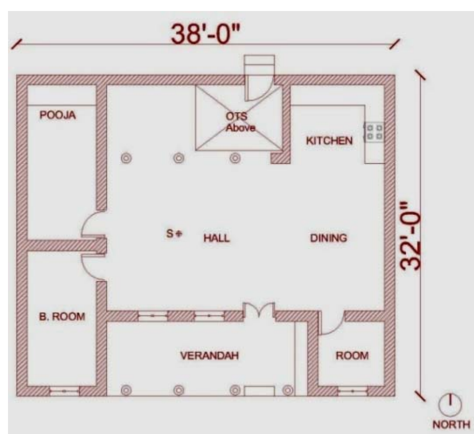
Considering these a new dwelling with solar passive architecture is designed with different architectural techniques and constructional elements. The present study aims to investigate the thermal comfort in the newly constructed solar passive residential building and compare its performance with that of a traditional building and modern building in the district of Thanjavur, Tamilnadu, South India. Thermal performance is analyzed in relation to climate and various aspects necessary for understanding such performances. A field study has been carried out in all the three buildings simultaneously during the most unpleasant hot summer season and the performance of these buildings are analyzed based on solar passive architecture.

II. EXPERIMENTAL INVESTIGATION

A. Building description

i. Traditional building-

(a)



(b)

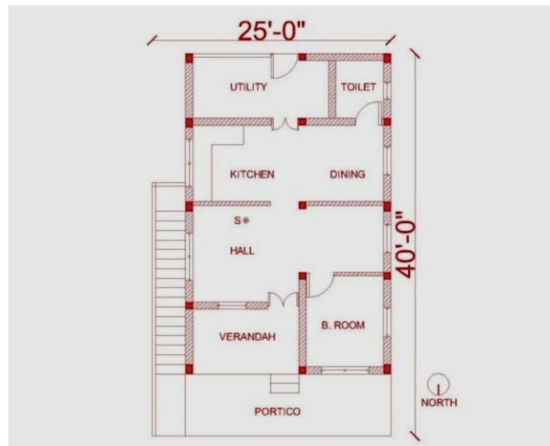
Figure 1. (a) Traditional house at Ariyacheri (b) Plan of the traditional building

A typical traditional residential building chosen for the investigation is located at Thanjavur district in Ariyacheari near Semangudi 40km from Thanjavur. Figure 1 shows the elevation and plan of the traditional building selected. The house has a rectangular courtyard surrounded by rooms on 3 sides with a total plinth area of 1200 sq. ft. The building is nearly 100 years old. Courtyard measures 8’ 9” x 6’ 6” located in the axis adjacent to the rear wall. The room height in the interior varies from 8’6” to 14’ 9” at the ridge. The sides of the courtyard are semi open spaces used as living spaces. This house is constructed using handmade bricks, clay and mud mortar with a wall thickness of 1 feet. The inward looking design with a courtyard is made as successful feature for thermal performance. Roof is made of Mangalore tile having ridges and slope. The building is mutually shaded by adjacent buildings on sides.

ii. Modern building-

Modern building used for comparison is chosen from the same locality at a distance of 100m from the traditional building. Figure 2 shows the elevation and plan of the modern building without Solar Passive Design (SPD) selected for the study. This building is 5 years old with around 1000 sq. ft. area. The house is constructed using 9” thick burnt brick external walls and 4.5” thick internal wall in burnt clay bricks and 10-15cm thick reinforced cement concrete roof. The internal height of the rooms is 10 feet. It has the most common layout that is generally seen in present day modern houses. The fenestrations are provided with sunshades of 60cm from wall for protection from rain and sun.

(a)



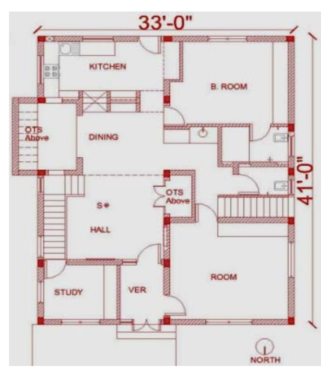
(b)

Figure 2. (a) Modern building without SPD at Ariyacheri (b) Plan of the Modern building without SPD

iii. Designed solar passive modern building-

A modern building with SPD has been constructed in Thanjavur. The view and plan of the building is shown in Figure 3. The built-up area is around 1200 sq. ft.

(a)



(b)

Figure 3. (a) View of the designed modern building with SPD (b) Plan of the designed modern building with SPD

Materials available in the commercial markets are used for the construction similar to the modern buildings without SPD so as to have a reasonable comparative analysis and to assess the impact of solar passive design strategies.

B. Thermal Comfort Conditions and Strategies

As per the ASHRAE standard 55-2004 “thermal comfort is the condition of mind that expresses satisfaction with the thermal environment”. Tropical summer Index (TSI) for warm humid climate in India has been developed. The thermal comfort conditions given in National Building Code (NBC) of India are based on the study of this Tropical Summer Index (TSI). According to NBC 2005, the thermal comfort limit of a person ranges from 25ºC to 30ºC. The comfortable indoor relative humidity ranges from 30% to 70% and the comfortable indoor air flow is in the range of 0-2 m/s. According to TSI, temperature between 30ºC and 34ºC is classified as comfortably warm which can be managed with sensible air movement of 1.5m/s [33-35].

C. Instrumentation

The parameters used for the analysis are indoor air temperature, humidity, air flow of the living rooms and the solar radiation outside. The readings are taken during hot summer on various days in March 2016. Measuring instruments and devices include (i) A digital anemometer MASTECH MS6252B used to measure relative humidity, ambient temperature and wind velocity (ii) A solar power meter TES 1333 used to measure the solar radiations of the location [36] (iii) HTC easy log data logger for measuring air temperature and relative humidity continuously.

III. Results and discussion

A. Solar Passive Design (SPD) strategies incorporated in Construction

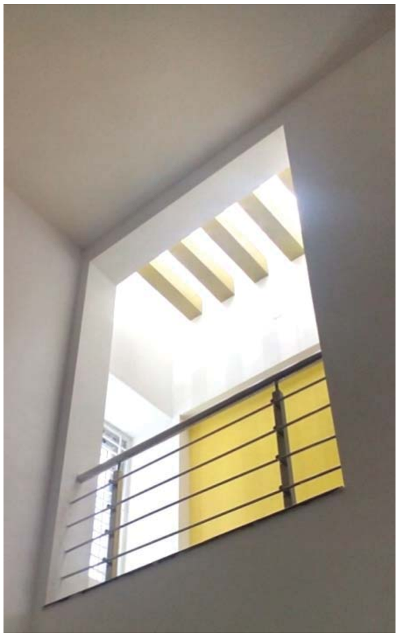
The new modern building is designed incorporating the following solar passive architecture design strategies – Building orientation, courtyard design, light coloured building exterior painting, heat reflecting roofing tiles, shading elements, solar chimney and sky light, good ventilation, landscaping, roof level ventilators and high ceiling roof. These strategies adopted can enhance the comfort of the occupants in solar passive buildings [37-45].

Building is oriented along North - South axis minimizing solar exposure to habitable rooms. Linear arrangements of rooms are planned with shading elements on the rear side and parking area portico in the front side. Shaded area avoids solar exposure and allows cool air to flow inside the building. A courtyard of size 3' x 10’ is designed in the house on the eastern side as shown in the figure 4(b). It allows light but not heat radiations into the living cum dining room. It also creates good air flow by convective cooling either upwards or downwards. Since white or lighter shades that have higher emissivity are most effective for warm humid climate, the designed building is completely painted in white colour to improve thermal performance by reducing heat gain through less absorption and maximum reflection. White roofing tiles with high solar reflective index are used for the roof. This significantly reduces the heat entering inside the building through conduction and provides better indoor thermal comfort.

All the openings in the building have shading elements to block solar radiation incident on the exposed surfaces of a building, consequently reducing heat gain and improve the performance the building. The sunshade is projected four feet on southern direction casting complete shadow on the walls facing south. Such overhang projection is made on northern direction which allows cool air and cuts heat radiation. Toilet spaces are well located along the western direction which acts as a buffer and also casts mutual shading along the west side thereby avoiding the long wave radiations on the western direction.

A combination of central courtyard with a solar chimney of size 3' x 6' is provided with a transparent roofing sheet as shown in figure 4(a). Solar chimney cum wind shaft is used to stimulate ventilation for passive cooling when air in a limited area is heated through solar insolation is ideal for warm and humid climate. A difference in temperature felt causes the hot air to move up under the convective principle and escapes out at top. The draft draws in the cooler air from the surrounding and thereby reduces indoor air temperature. This improves the cooling effect inside the building. This also acts as sky light and also as an air shaft, bringing both day light and air circulation in the living space and rooms around. This enhances continuous flow of air inside the building and thereby keeps the indoor temperature down. Also adequate day lighting is provided throughout the day in all the areas of the designed house resulting in zero energy consumption for artificial lighting.

Cross ventilation is the prime importance in warm and humid tropical climates with protection of roof to avoid heat gain. As per the solar passive concept of architectural design, the alignment of openings, window placement in all the rooms, front and back door along the central axis, courtyard at the centre part and a buffer courtyard promotes good airflow. Optimum number of openings on exterior wall, inward looking plan and open plan without much internal wall provides good privacy, comfortable indoor temperature and required lighting everywhere inside the house. Trees and plants are used on the southern direction to shade the building and avoid heat radiations falling on the wall. Roof level ventilators are provided to vent hot air. The roof is designed in such a way that vents at the roof top effectively induce air flow and also draw hot air-out.



(a)

(b)

Figure 4. (a) Solar chimney cum wind shaft in the designed house (b) Courtyard view in the designed house

The thermal inertia of indoor environment is directly proportional to the volume of that environment according to thermodynamics and heat transfer principles. In tropical countries with hot weather locations during most of the period, if ceiling heights are increased it causes a small decrease in indoor temperature of environment. The ceiling height in a part of the living room alone is raised up to 18 feet incorporating roof level ventilators and solar chimney on other side of the room. This contributes to the reduction in the indoor air temperature at human occupancy level as heated air rises up towards the vent above. The impact of incorporating solar passive architecture design helps in reducing the operative cost and makes the whole building energy efficient.

B. Thermal Comfort Analysis

Figure 5 shows the comparison of indoor air temperature between the selected traditional building, modern building without SPD and designed building with SPD for corresponding ambient outdoor temperature. From the readings it is observed that the ambient outdoor temperature has a diurnal swing of 15.2 ºC, i.e. from 23 ºC to 38.2 ºC, while the indoor room temperature of the traditional building was varying from 24 ºC to 30.8 ºC showing a diurnal swing of about 6.8 ºC. It is observed that the indoor temperature falls within the comfort range of ASHRAE & TSI standards. In the modern building without SPD selected for comparison, the indoor room temperature varies from 28.9 ºC - 33.9 ºC showing the diurnal variation of 5ºC. The maximum air temperature measured for the living room is about 33.9 ºC. This shows that the indoor temperature of the modern building without SPD is not within the comfort zone according to ASHRAE & TSI standards. During the study period, the solar radiation is found to vary from 470 W/m2 to 1280 W/m2 with around 8 hours of sunshine each day. In the designed modern building with SPD, the indoor room temperature varies from 27.4 ºC - 30.8 ºC showing the diurnal variation of 3.4 ºC. The maximum air temperature measured for the living room is about 30.8 ºC. This shows that the indoor temperature of the modern building with designed with SPD is well within the comfort zone according to ASHRAE & TSI standards.

Decrease in temperature in the designed building is attributed due to the solar passive design features such as orientation and planning, courtyard design, light coloured painting, white roofing tiles, shading elements, solar chimney and sky light, cross ventilation, landscaping, roof level ventilators and high ceiling roof. But the other modern building has similar construction materials without consideration of solar passive cooling features. The reason for the thermal discomfort in the other modern building (without SPD) in Thanjavur is due to the increase in air temperature, relative humidity (RH) and absence of required airflow, which is attributed due to improper design.

The indoor air flow in the designed house with SPD is within the comfortable range of 0-2 m/s as per the standards. The air flow is negligible or less than 0.4 m/s in the house without SPD showing uncomfortable for occupants as per standards. This is due to the reason that airflow enhances the comfort aspects of the indoor when the temperature or humidity rises up beyond the required limit.

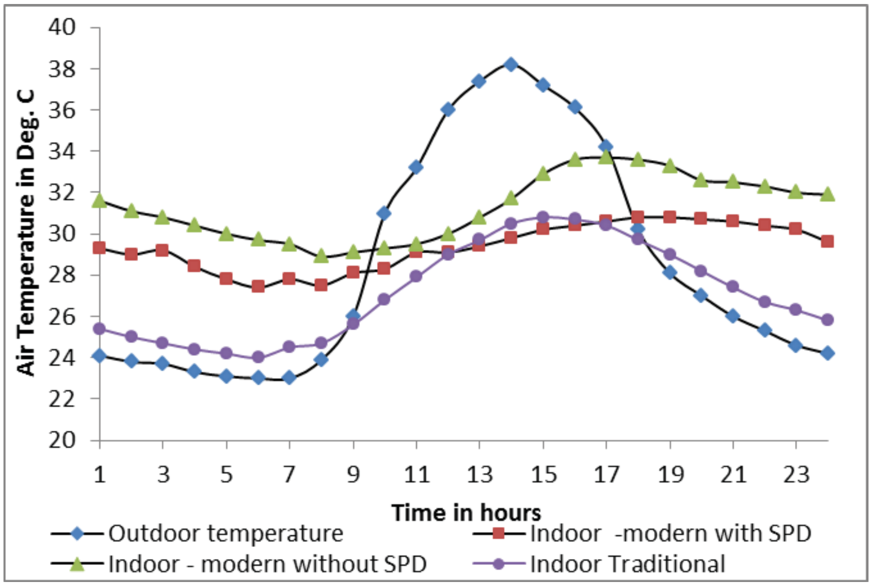


Figure 5. Comparison of indoor air temperature between the designed modern building with SPD, without SPD and traditional for the corresponding ambient outdoor temperature

Figure 6 shows the comparison of relative humidity between the selected traditional building, modern building without SPD and the designed modern building with SPD for the corresponding outdoor relative humidity. The relative humidity of the outdoor varies from 41.9% to 89.3% during the study period. The relative humidity inside the traditional house varies from 59% to 84.1%. But in the house without SPD, the relative humidity ranges from 56.8% to 78.2%. This is slightly in the uncomfortable zone as per standards. By incorporating SPD aspects the designed house brings down the relative humidity which ranges from 46.4% to 74%. This is in the comfortable range of 45% - 70% as prescribed by ASHRAE & TSI standards.

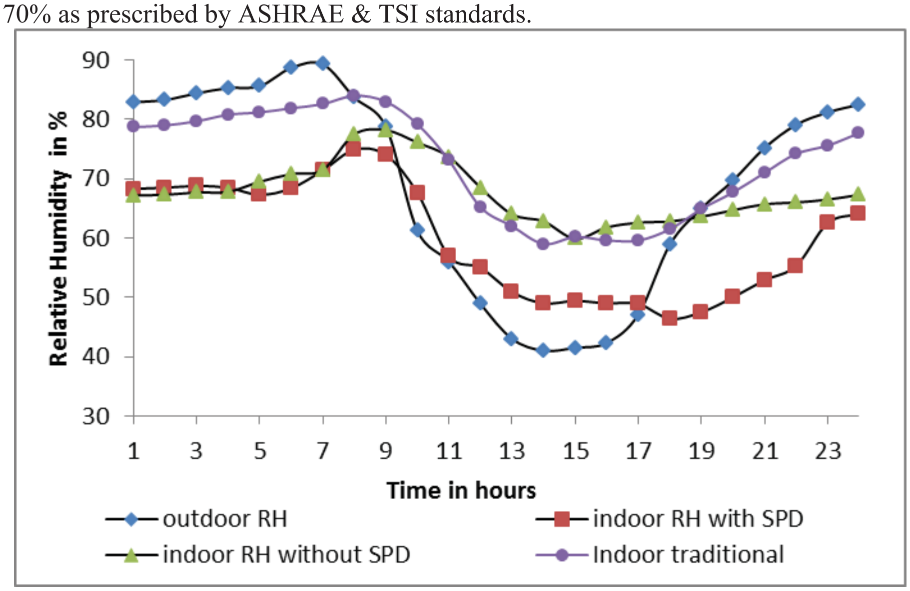


Figure 6. Comparison of relative humidity between the selected modern buildings with SPD and without SPD for the corresponding outdoor relative humidity

In the house without SPD the average discomfort period is found to be 10 hours per day whereas in the designed house with SPD the occupants feel comfort throughout the day. In the traditional houses, the continuous air flow is available at the speed of 0.4m/sec to keep the indoor cool inspite of increase in the indoor humidity levels.
The occupants in the house without SPD require auxiliary appliances such as fan or air-conditioners to make their stay comfortable. But occupants in the designed house with SPD as in traditional buildings are comfortable even without electrical gadgets. This helps in saving energy consumption which is the need of the hour.

C. Bioclimatic chart Analysis

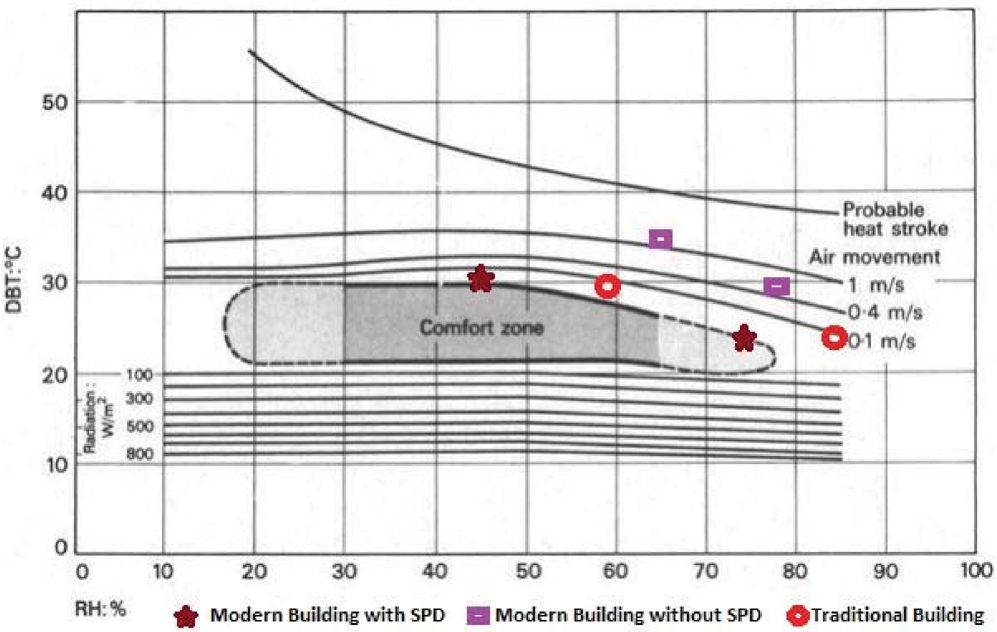


Figure 7. Bioclimatic chart showing the readings during maximum temperature or maximum humidity for different buildings[46].

During the study period in summer, the indoor temperature of traditional building under investigation is high up to 30.8 ºC with humidity of 60%. This falls within the comfort region of the Bioclimatic chart and also very near to the comfort zone (Fig. 7), since the air speed maintained inside the building is around 0.4 m/s [46]. The indoor comfort condition of traditional building is not affected even when the temperature becomes as low as 24 ºC during night time with the increase in humidity (up to 84.1%). Thus the continuous air flow (maintained around 0.4 m/s) inside the building provides thermal comfort even at a high humidity as per the Bioclimatic chart.

In the modern building without SPD, during summer period when the indoor temperature is high up to 33.9 ºC, the humidity is 63.6%. This does not fall even in the comfort region of the Bioclimatic chart since the air speed measured inside the building is negligible and the temperature is very high. During nights, even though the temperature is around 28.9 ºC, the absence of air flow and increase in humidity (upto 77.5%) results in discomfort.

In the designed modern building with Solar Passive design shows the indoor temperature is high up to 30.8 ºC, the humidity is 47.5%. Even without the use of any electrical gadgets and without air flow, the indoor is comfortable and falls well within the comfort zone of the Bioclimatic chart. In addition the air flow is also found in the range of 0.2-0.4 m/s. During night, since temperature becomes as low as 27.4 ºC, the increase in humidity (up to 68.4%) does not affect the indoor comfort condition of designed building as per the Bioclimatic chart.

IV. CONCLUSION

Detailed investigations carried out on the three buildings i.e traditional building, modern building without SPD and the designed building with SPD indicates that solar passive techniques contributed for bringing indoor temperatures down for thermal comfort to occupants of residential buildings in Thanjavur region. It is found that solar passive designed building maintains a comfort temperature range of 27.4 ºC to 30.8 ºC and humidity range of 46.4% to

74.9% during study period which is well within the comfort temperature of the region as per ASHRAE, TSI thermal comfort standards and Bioclimatic chart. Further the traditional building performs well and it is near the comfort range and falls within the comfort zone due to the presence of continuous air flow (maintained around 0.4 m/s) inside the building. Whereas in the modern building without SPD, during summer days the indoor temperature is high up to 33.9 ºC, the humidity is 63.6%. As per the Bioclimatic chart, this does not fall even in the comfort region since the air speed maintained inside the building is also negligible and the temperature is very high.

During hot summer the indoor temperature of the designed solar passive building is much lower than the outdoor ambient temperature. It is also observed that the indoor temperature of the designed solar passive building is similar to that of traditional building which is 2-3 ºC cooler than the modern building without solar passive design.

The ultimate aim of providing thermally comfortable and energy efficient building is thus achieved by incorporating solar passive design strategies with available modern building materials. This plays a significant role to save energy creating a great impact on economy both at national and global level. So, it is a boon for Architects and building designers to incorporate such solar passive design strategies in all new constructions and also to incorporate in existing buildings that lack thermal comfort.

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