Design and Analysis of Solar Passive Architecture for Thermal Comfort of Residential Buildings in Warm-Humid Climate of Thanjavur Region

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Abstract

Objectives: To design and construct a contemporary residential building in warm and humid climate of Thanjavur with solar passive architecture concepts that can make the building thermally comfortable like traditional buildings. Methods/Analysis: Solar passive architecture concepts and principles are used in traditional buildings worldwide. Thermal performances of such traditional buildings are well within the comfort range as prescribed by thermal comfort standards. But in most of the contemporary buildings, the indoor environmental conditions and thermal comfort are unsatisfactory due to improper design. Hence an attempt has been made to design and construct a contemporary residential building with solar passive designs. Thermal performance analysis is carried out during summer in the designed building and is compared with another contemporary house. Findings: The study on designed solar passive house indicates that improved performance can be achieved by combining the lessons learnt from traditional buildings by incorporating solar passive techniques that can bring indoor temperatures down enough for comfortable indoor environment to the occupants. It is observed that the temperature of the designed solar passive building is 2ºC to 3ºC cooler in summer in comparison with the contemporary building. It is evident from the study that design of building plays a major role to save energy which in turn gives an impact on national and global economy. These design findings can be applied further to contemporary residences in any context with reference to its local climate. Novelty/Improvement: Ten solar passive architecture strategies have been incorporated in the designed building which include 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.

Keywords: Contemporary Buildings, Solar Passive Architecture, Thermal Comfort Standards, Warm-Humid Climate

1. Introduction

Accelerated urbanization and rapid change in the living standard has imposed immense pressure on the dwindling energy sources, thus aggravating the already rampant process of environmental degradation due to large consumption of energy and natural resources. The operations of buildings worldwide contribute up to 40 percent of total global energy consumption.

The basic need of all buildings is to adapt regional climatic conditions that will provide conducive and comfortable environment to the dwellers. The traditional
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Building are considered as prime examples for their environmental design in response to the regional climatic conditions and making it more energy efficient. Now building designers face challenges to provide buildings constructed with modern building materials that will be comfortable and suitable for the 21st century.

Literature survey shows that the performance of the thermal environment of traditional houses is comparatively better than the modern structures due to the presence of solar passive features - courtyard, thick walls, tiled roofs and natural ventilation. The indoor environmental conditions and thermal comfort in contemporary houses are unsatisfactory due to improper design. Minimum of 10 to 20 percent energy can be saved in the native architecture compared with contemporary structures to keep the indoor comfortable. A minimum 2 to 3ºC cooler temperature can be achieved in summer with such traditional houses. In contemporary buildings, the energy used for maintaining thermal comfort is expected to mount up over the coming days, which will move the situations worse due to an intermittent and unreliable status access to electricity supply in India.

There is also flexibility in building design to make it more energy efficient by introducing solar passive architecture features. Indoor environment comfort level can be improved by doing certain modifications in the existing houses too. Climatically designed building enhances thermal comfort conditions inside the house which in turn reduces operational as well as embodied energy consumption.

As an adverse impact, energy efficiency of the traditional buildings is affected by gradual change of old building materials by available modern building materials while preserving such structures. It also renders the building with improper climatic design and leaves the indoor thermal environment into uncomfortable zone. In the era of globalization, it is necessary to validate and highlight the thermal passive principles adopted towards thermal comfort.

Hence in the present work, an attempt has been made to design and construct a residential building in the warm humid climate of Thanjavur, Tamilnadu, South India with solar passive architecture concepts. The objective of the work is

- To study the thermal performance of the designed solar passive architecture building.
- To validate and highlight the solar passive principles adopted towards thermal comfort.
- To compare the thermal performance of designed house with another contemporary house nearby in that region.

2. Methodology and Instrumentation

2.1 Thermal Comfort Conditions and Strategies

Comfort of the occupants does not occur at fixed temperature as it depends on various physiological parameters like clothing, metabolic activities and environmental parameters like airflow, solar insolation and relative humidity. ASHRAE standard 55-2004 states "thermal comfort as the condition of mind that expresses satisfaction with the thermal environment". Internationally ASHRAE standards are commonly followed for various thermal comfort analyses in which it is mentioned that the comfortable indoor temperature for summer is from 22.22ºC to 26.66ºC and the comfortable indoor relative humidity ranges from 30% to 60%. Givoni B has provided strategies for developing countries using bioclimatic charts and has stated the acceptable range of temperature in summer is between 20ºC to 29ºC for still air. Tropical Summer Index (TSI) has been developed for hot-dry climate and warm humid climate in India. The thermal comfort conditions given in National Building Code (NBC) of India are based on the study of the 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 1.5 m/s.
2.2 Location
Thanjavur is a small city located in the southern part of India at 10º 48’N latitude and 79º 9’E longitude and has an elevation of 88m above MSL\(^2\). Thanjavur is classified under warm humid climate region in the climate zone of India\(^3\). Hot months of the region are March to June with maximum mean temperatures ranging from 35-36 ºC and cool months are November to January with minimum mean temperature ranging from 23-24 ºC. According to Indian Meteorological Data (IMD), the maximum temperature from March to June in the study location ranges from 41-43 ºC. North-East monsoon between October and December contributes 54% main monsoon out of mean annual rainfall of 945 mm.

2.3 Details of the Houses Selected for the Present Study
In the present study a contemporary house designed and constructed with Solar Passive Design (SPD) strategies and a house with regular market driven contemporary strategies without Solar Passive Design are selected for investigation. The houses selected for the study are in same locations in Thanjavur within a distance of 50 metres. Figure 1 and 2 shows the view and plan of the contemporary building without SPD respectively.

![Figure 1. View of the contemporary building without SPD.](image)

The orientations of both the buildings are similar along North-South direction with east wall exposed to sun adjacent to living room. Both are individual houses with a plinth of around 1200 sq ft in Ground floor. Thermal comfort analysis is carried out for living cum dining room in both the houses, in particular, as most of the time the occupants spend in this zone. Both the houses have similar wall type construction and plastering made of burnt bricks with external and internal walls of thickness 23 cm and 11.5 cm respectively. The roof slab is made of Reinforced Cement Concrete (RCC) of thickness 12-15 cm. Both the buildings have shading devices with 0.6 m projections at all window openings. The building with SPD has roof overhangs at front and back side of the building providing shade on the walls. The contemporary building has light coloured exterior walls. Building with SPD is painted white on exterior. In both the buildings used for study, the sizes of the windows are either 4’ x 5’ or 4’ x 3’ as per the positions shown in the plans of the buildings. The building with SPD in addition has two courtyard openings in the roof.

![Figure 2. Plan of the contemporary building without SPD.](image)

2.4 Instrumentation
The parameters used for the analysis are indoor air temperature and humidity of the living rooms. The readings are taken during hot summer on various days of May and June. Measuring instruments and devices include 1. A digital anemometer MASTECH MS6252B used to measure relative humidity, ambient temperature and wind velocity. 2. A solar power meter TES 1333 used to measure the solar radiations of the location\(^4\). 3. HTC easy log data logger for measuring air temperature and relative humidity continuously. 4. INFRARED DT 8380 thermometer for measuring surface wall and roof temperatures. 5. HTC Digital Lux meter LX-101A to measure Illumination levels.
3. Results and Discussion

3.1 Solar Passive Design Strategies Incorporated

The contemporary building is designed incorporating the following ten solar passive architecture strategies-orientations 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. These strategies adopted can enhance the comfort of the occupants in solar passive buildings. Figure 3 and 4 shows the view and plan of the designed contemporary building with SPD respectively.

3.1.1 Orientation and Planning

North-South orientation is adopted with minimum exposure to habitable rooms. The aspect ratio of the house plan 1:1.6 (55’ x 33’) which is in ‘golden proportion’ is pleasingly harmonious. This is designed by linear arrangement of two rows of rooms, front row being shaded by portico. Shaded area avoids heat radiations and allows cool air to flow in.

3.1.2 Courtyard Design

Figure 5 shows the view of the buffer courtyard of size 3’ x 10’ on the eastern side in the designed house on a hot summer day.

Figure 3. Plan of the designed contemporary building with SPD.

Figure 4. View of the designed contemporary building with SPD.

Figure 5. View of buffer courtyard with dry garden in the designed house.

Compactness in planning allows light but not heat radiations through the buffer courtyard with dry garden adjacent to living cum dining room. The buffer courtyard creates good air flow by density difference creating a draft pulling air either upwards or downwards.

3.1.3 Light Coloured Painting

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 through light coloured walls.
3.1.4 White Roofing Tiles

In residential buildings, heat transmission across the building roof is about 50-70% of the total rooms below the exposed roof. Covering roof top with white tiles with highly reflective coatings having more solar reflectance is found to reduce 20-70 percent heat transmission through the roof. Solar reflectance is increased by white roofing tiles, which has high solar reflective index. This significantly reduces indoor building temperature and provides better thermal comfort.

3.1.5 Shading Elements

All the fenestrations have shading elements to block solar radiation incident on the exposed surfaces of a building, consequently reducing heat gain. Such shading elements can significantly improve the performance of the building. Apart from shading elements for fenestrations 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 in plan along the western direction which provides a buffer and also casts mutual shading along the west side. The long wave radiations on the western side are cut to the maximum by locating such buffer rooms.

3.1.6 Solar Chimney and Sky Light

Stimulated ventilation for passive cooling is ideal for warm and humid climate in which air in a limited area is heated through solar insolation. This can be provided using a solar chimney. A difference in temperature felt causes the hot air to move up under the convective principle and escapes out. The draft draws in the cooler air from the surrounding and thereby reduces indoor air temperature. This improves the cooling effect inside the building. A combination of central courtyard with a solar chimney of size 3’ x 6’ is provided with a transparent roofing sheet. Figure 6 shows the view of the solar chimney cum wind shaft located exactly at the central part of the designed house. This acts as sky light and also as an air shaft, bringing both day light and air circulation in the living space and rooms around. The pressure difference thus created pulls the air from the living space and the rooms around, rises up generating an upward draft and exhausts through the openings at the top. This enhances continuous flow of air inside the building and thereby keeps the indoor temperature down.

3.1.7 Cross Ventilation

Cross ventilation is 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.

3.1.8 Landscaping

Planting of trees at strategic locations and shadow casted improves the indoor thermal comfort of buildings. Evergreen trees are used on the southern direction to shade the building and avoid heat radiations falling on the wall.
3.1.9 Roof Level Ventilators

Outlets at higher levels and roof level ventilators serve to vent hot air. The form of the roof is designed in such a way that vents at the roof top effectively induce air flow and also draw hot air-out. The solar chimney design of living room also adds upward draft that vents hot air out.

3.1.10 High Ceiling Roof

The thermal inertia of indoor environment is directly proportional to the volume of that environment according to thermodynamics and heat transfer principles. For 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 of the living room is increased by 9' 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 vent above.

The impact of incorporating solar passive architecture design helps in reducing the electricity consumption.

3.2 Thermal Comfort Analysis

Figure 7 shows comparison of indoor air temperature between the selected contemporary buildings with SPD and without 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 contemporary building with SPD was varying from 25.6 ºC to 30.2 ºC showing a diurnal swing of about 4.6 ºC. It is observed that the indoor temperature falls within the comfort range of ASHRAE & TSI standards.

In the other contemporary building without SPD selected for comparison, the indoor room temperature varies from 29ºC - 33.4ºC showing the diurnal variation of 4.4ºC. The maximum air temperature measured for the living room is about 33.4ºC. This shows that the indoor temperature of the contemporary building without SPD is not within the comfort zone according to ASHRAE and TSI standards. During the study period, solar radiation is found to vary from 450 to 1200 W/m² with 8-9 hours of sunshine each day.

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 contemporary building has similar construction materials without consideration of solar passive cooling features. The reason for the thermal discomfort in the other contemporary building (without SPD) in Thanjavur is due to the increase in air temperature and relative humidity (RH) which is attributed to improper design.

The indoor air flow in the designed house with SPD is within the comfortable range of 0.2-0.4 m/s as per the standards whereas the air flow ranges from 0-0.2 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 8. Comparison of relative humidity between the selected contemporary buildings with SPD and without SPD for the corresponding outdoor relative humidity.
Figure 8 shows the comparison of relative humidity between the selected contemporary buildings with SPD and without SPD for the corresponding outdoor relative humidity. The relative humidity of the outdoor varies from 42% to 90% during the study period. By incorporating SPD aspects the designed house brings down the relative humidity which ranges from 45.8% to 70.6%. This is in the comfortable range of 45%-70% as prescribed by ASHRAE and TSI standards. But in the house without SPD, the relative humidity ranges from 59.9 to 73.2. This is slightly in the uncomfortable zone as per standards.

From Figure 7 and Figure 8 it is also evident that in the house without SPD the average discomfort period is found to be 10 hours per day (14.00- 24.00) whereas in the designed house with SPD the occupants feel comfortable throughout the day. The occupants in the house without SPD require auxiliary appliances - fan or air-conditioners to make their stay comfortable as prescribed by ASHRAE and TSI standards. But occupants in the house with SPD are comfortable even without electrical gadgets. This helps in saving energy consumption which is the need of the hour.

4. Conclusion

Thermal comfort is a basic requirement of any building which can be achieved through solar passive design strategies. Hence the design of such energy efficient buildings plays a major role to save energy which in turn gives an impact on national and global economy.

The studies on solar passive designed house indicate that solar passive techniques can bring indoor temperatures down for thermal comfort of occupants of a residential building in Thanjavur region. It is found from the study that solar passive designed building maintains a comfort temperature (25 °C to 30 °C) during summer season which ranges well within the comfort temperature of the region as per ASHRAE and TSI thermal comfort standards. Indoor air temperatures are comparatively much lower than the outdoor air temperatures in hot summer. Compared to other contemporary building without SPD, the solar passive designed building is 2-3 °C cooler in summer as observed in the traditional buildings.

So, it is evident that solar passive building has its own merit in maintaining thermal comfort. The study and results will be an eye opener for Architects and Engineers to adopt solar passive architecture in contemporary constructions and also to incorporate in existing buildings while retrofitting the structures to improve comfort and energy efficiency.

Awareness on solar passive architecture, Law enforcement, Guidelines and allowances for buildings with SPD can be created in the byelaws in order to embrace landlords and house makers to efficiently follow this Solar Passive Designs.

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