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Summer Thermal Performance of a Multistoried Residential Building

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Abstract: *Individual residential houses occupy a large area of land space. But multi storied buildings reduces the use of larger land area than the individual residential houses. A multi-story building is a building that supports two or more floors above the ground.A Single storey or multi-storey building is an active system. Thermal variation in the outdoor brings out thermal variations in the indoor. The roof of a single storey building receives the solar radiations directly and in the case of multi-storey building the top floor alone receives. The walls of the both type of buildings receive the solar radiations directly. The radiations from the roof and walls are propagated to the inside of each indoor of a multi-storied building. In a multi storied building the indoor temperature increases slowly to a steady state. Even if the outdoor temperature falls, the indoor temperature of the building does not fall. There exists a time lag for the rise and fall with the outdoor.Hence this study has been aimed to measure the inside roof, inside walls and indoor temperatures of the different floors. It has been observed that there are noticeable variations in the roof, walls and indoor temperatures between different floors.*

Keywords: *Individual houses, Multi storey building,Roof temperature, Wall temperature, Indoor temperature, Comfort, Thermal efficiency*

I. Introduction

A building is a man-made structure with a roof and walls standing permanently in one place. A house or factory building comes in a variety of size, shape, and function. Buildings are built from available materials depending on the weather condition, land price, ground condition, specific use and aesthetic reason. Buildings provide shelter from weather, security, living space, privacy, to store belongings and to get comfortable living and to work. A building as a shelter represents a physical division of a place of comfort and care from the harsh outside.

A multi-story building has two or more floors above the ground. The height of the multi- storied building is eye-catching. Its elegant appearance astonishes the viewer. There is no formal restriction on the height of such a building or the number of floors, a multi-story building may contain. In a multi-storey building, the frame is a three-dimensional structure or a space structure. It is perfect as a system of interconnected two-dimensional vertical frames along with the two mutually perpendicular horizontal axes. And further a building is subjected to various loads such as dead load, live load, lateral load, wind load or earthquake load. Too tall buildings are subjected to face more practical problems than others.

Reinforced concrete buildings consist of floor slabs, beams, girders and columns continuously placed to form a rigid monolithic system. Such a continuous system leads to greater redundancy, reduced moments and distributes the load more evenly. The floor slab may rest on a system of interconnected beams. The load bearing capacity of the building depends on the size of the steel rods which are embedded in the concrete mixture. The steel is a good conductor of heat. The reinforced concrete is a high thermal mass material. High Thermal Mass material (HTM) possesses the ability to absorb and store heat energy. HTM can store solar energy during the day and re-radiate it at night.

HTM moderates internal temperatures with respect to the diurnal (day and night) variations. Use of HTM materials in the construction is generally not recommended in hot and humid climates due to their limited diurnal range. But the population growth, the urbanization and the land scarcity pushes to construct multistoried buildings.

The top floor of the roof is subjected to direct heating by the solar radiations during most of the hours of the day. The eastern side walls and the western side walls of the building are subjected to direct heating in the morning and evening hours respectively. The primary source of heat is the Sun. The buildings gain heat from the solar radiations during the day time. They reradiate heat not only to the indoor but also to the outdoor. The tropical climate multi storey buildings retain more heat.

1. Factors Influencing the Thermal Interaction

There are two factors which affect the thermal performance of a building. The first type is the unsteady climatic conditions to which the building is exposed. This includes the reception of solar radiation (direct, diffuse and reflected), outdoor temperature, relative humidity and wind speed.

The second type is the design features related to the building which includes the size, orientation and colour of the walls and roofs, shading conditions, the size and location of the windows from the ventilation aspect and the thermo physical properties of the building materials.

The indoor temperature is a combination of radiations received through the roof and walls of the building and through ventilation systems. Furthermore the indoor temperature will be increased due to the heat sources in use within the building. The too high or too low indoor temperature of the building provides thermal discomfort. Too high indoor temperature leads to air condition the building to get comfort level. Too cold condition leads to heat the indoor to get comfort. In the above two high and low temperatures, thermal performance of the building is said to be poor regarding the occupants. Decreasing or increasing the indoor temperature to a pleasing level of the occupants leads to comfort temperature. In a monolithic structure, the roof and walls are constructed with the same proportion of materials. The primary material in the roof, columns and beams are the steel rods of different size, which is the major conductor of heat in the building shell.

During hot days especially in summer, the heat absorption mainly takes place through the roof and is conducted to the steel rods in the roof. Then the heat flow is distributed to the other interconnecting steel rods. Whatever be the heat absorbed it will be transmitted to the steel rods from the top to the bottom of the structure. Continuous absorption of heat keeps the top floor to be at a high temperature than the other floors. The heat received by the ground floor is relatively less than the top floor.

Comfort is determined by the indoor temperature of a living place. The indoor temperature is determined by the roof and wall temperatures and the ventilation level. The study of the roof and wall temperatures leads to find out indoor temperature and its deviation from comfort temperature. From this indoor temperature, the comfort percentage or the thermal efficiency of the building can be determined.

Comfortable living increases the use of electrical energy. Instead of individual houses, people like to prefer residence in the multi-storied buildings. There are advantages in their choice. The individual need not strain to construct his own building. The loneliness found in the individual habitat disappears. The land requirement also shrinks for the builder. Hence the high rise buildings are predominant all over the world.

Indian concrete roofs in single or two storey buildings with 150mm thickness of reinforced cement concrete (RCC) and a weathering course (WC) having 75 -100mm thick lime brick mortar, account for about 50% - 70% of total heat transferred into the occupant zone and are in charge for the major portion of electricity bill in air conditioned buildings [1].

As per ASHRAE (1990b) [2], energy resources are fundamental ingredients of all the economic systems. Efficient use of energy is important since the reserve of our global energy resources is finite and depleting. Energy use in building involves the parameters which are complex and diverse in nature. Design of energy efficient building is still not widely encouraged and suffers by lack of appreciation for different reasons. Guided by the market forces, many architects even never bother to design the buildings considering the climatic constrains and focus mainly on the aesthetic aspects, sometimes even follow the negative effect of technology. The building sector plays an important role in the energy consumption.

According to the Earth Trends Country Profile 2003, the Indian residential sector consumes about 201,000 MToe. (Million tons of oil equivalent), which is about 11% of world's energy consumption in residential sector [3]. It is noted that in the residential and commercial sector, there has been a rapid increase in the consumption of electricity at a rate of about 13.2%.

Research performed in Bangkok for improving thermal comfort in non-conditioned building in hot and humid climate reveals that thethermal performance of a multi storied residential apartment is a matter of concern in warm and humid and hot and dry climate[4].The heat transferred into the occupant zone is true for single storey and top floor of the multi-storeyed buildings [5].

Studies were reported on energy-efficient building envelope design for East Africa, where some basic energy-saving techniques have been recommended to reduce building energy consumption[6].A comparative analysis has been done on the thermal performance of non-air-conditioned buildings with a vaulted roof and a flat roof under different climatic conditions [7].A study performed on wall/roof thermal Performance differences between air - conditioned and non- air – conditioned roomsfound that in an air-conditioned room the most important physical property of the wall / roof is its thermal conductivity, which has to be as small as possible, while for the non- air conditioned room the most important physical property is the thermal diffusivity, which also has to be as small as possible[8].

In the urban areas, these multi-storied apartment buildings have major share in residential accommodations. The individual flats / apartment units of these buildings differ from each other in respect of orientation, openings, shading, exposed external surface etc. leading them to respond differently in terms of thermal behaviour. The factors controlling the comfort within a building are indoor temperature, indoor humidity and air-flow.

This field of research is important as the energy consumption of a building is associated with its thermal performance over the entire year and also the indoor thermal environment in the early summer has a carry-over effect of the previous winter due to thermal inertia of the building envelope. Heat exchange processes at a building, being considered as a defined unit, with the outdoor environment [9].

II. Research Description

A three storied brick masonry residential building at Chidambaram, Tamil Nadu has been considered for the test purpose. The experiments were carried out exactly in Chidambaram, Tamil Nadu, 11˚24´N latitude and longitude 79˚44´E. The experimental observations were recorded for a period of one year, namely, 12 months.

The study included the temperature measurements of the inside roof, inside walls and the indoor. The outdoor ambient temperature was obtained from the weather station. The aim was to find out the indoor temperature variations between different floors. Further to find out the percentage of comfort or thermal efficiency of the different floors.

Construction Data of the experimental building

Table.1 Data of the experimental building

Construction	Area (m^2)
Roof	144
External walls	540
Internal walls	210
Floor	560
Windows	4.5
Doors	12.8

Table.2 Material data for the different mixed concrete (from Herlin and Johansson 2011)

Material	**Volumetric Heat capacity(MJ/m^3K)**	**Thermal conductivity(W/mK)**
Exp. graphite concrete	1.5	3.5
Normal concrete	1.8	2.2
Copper fibre concrete	1.8	3.6
Steel fibre concrete	1.9	2.6
Magnetite concrete	2.3	2.6

III. Experimental Procedure

Three floors of the multi- storied building has been considered for this study. The ground floor of the building has been designated as GF. The first floor of the building has been designated as FF. The second floor of the building has been designated as SF. The inside roof temperature and the inside wall temperature of the four walls were measured using Infra-Red thermometer. The indoor temperature was recorded by single channel data loggers. The experimental observations were recorded for a period of one year from September 2013 to August 2014. For simplicity it has been taken for the month of April 2014. Inside roof, inside wall temperature means measurement of temperature from the interior side of the building. The inside roof, inside walls and indoor temperatures were measured three times of a day namely 6 hours, 14 hours and 18 hours. For the comparisons, 14 hours measurements have been considered.

IV. Results And Discussion

1. Inside Roof Temperature Of Different Floors

Fig.1 shows the relationship between the roof temperatures of the three floors during the peak hours of the day in the summer month of April. The roof temperatures of the three floors along with the outdoor temperature have been compared.

The roof temperature of the ground floor (T_{RGF}) has fluctuated between 33.8˚C and 35.6˚C. The roof temperature of the first floor (T_{RFF}) has oscillated between 34.4˚C and 35.9 ˚C. The roof temperature of the second floor (T_{RSF}) has varied between 34.8˚C and 37.2˚C.

The monthly average roof temperature of the ground floor was 34.56˚C. The monthly average roof temperature of the first floor was 35.17˚C.The monthly average roof temperature of the second floor was 36.11˚C.The monthly average outdoor temperature was 39.75˚C.

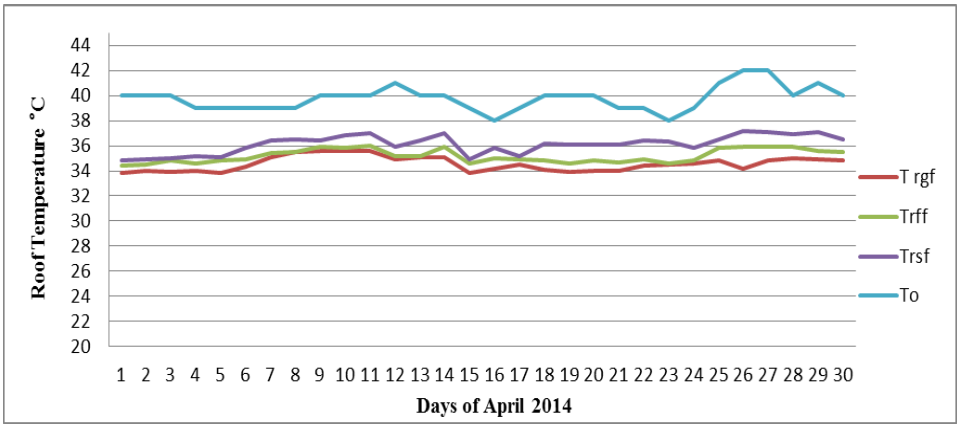


Fig.1 Roof temperature of different floors with the outdoor temperature

The roof temperature of the ground floor (T_{RGF}) shows a lower value than that of the other two floors. The roof temperature of the first floor (T_{RFF}) is lower than the second floor. The roof of the second floor (T_{RSF}) shows a higher temperature than the other two for the monitoring period. But the roof temperatures of the three floors are lesser than the outdoor temperatures.

2. Inside Wall Temperatures

Fig.2 shows the relationship between the wall temperatures of the three floors during the month of April 2014. The mean wall temperature of each floor was found and that temperature is here cited as wall temperature. The wall temperatures of the three floors along with the outdoor temperature have been compared.

The wall temperature of the ground floor (T_{wgf}) wavered between 33.3˚C and 35.2˚C. The wall temperature of the first floor (T_{wff}) varied between 34.4 ˚C and 35.5 ˚C. The wall temperature of the second floor (T_{wsf}) varied between 34.9 ˚C and 36.9 ˚C. The Outdoor temperature ranged between 39˚C to 42˚C.

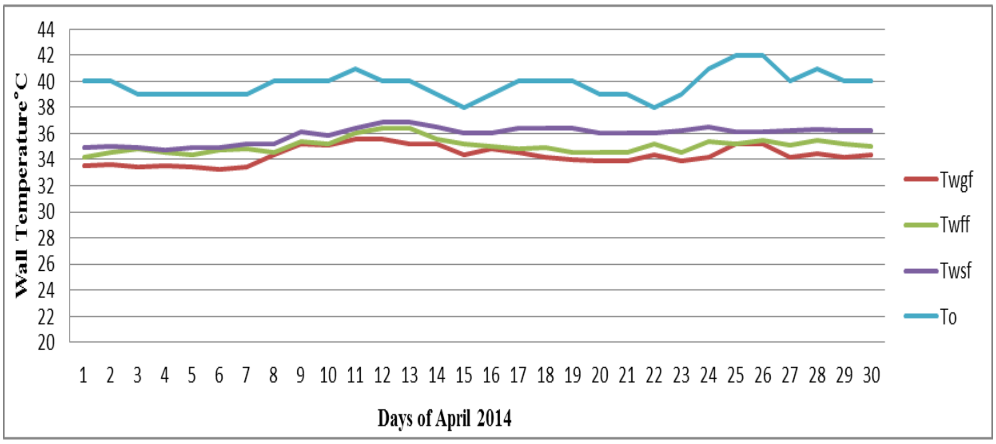


Fig.2 Inside wall temperatures of the four walls of the different floors

The monthly average wall temperature of the ground floor was 34.35˚C. The monthly average of the wall temperature of the first floor was 35.07˚C. The monthly average wall temperature of the second floor was 35.91˚C. The monthly average outdoor temperature was 39.75˚C. During the peak hours of the day the walls of the three floors showed different temperatures.

3. TheIndoor Temperature of Different Floors

Fig.3 showsthe relationship between the indoor temperatures of different floors.The indoor temperature of the ground floor (T_{IGF}) was fluctuated between 33.4˚C and 34.1˚C. The indoor temperature of the first floor (T_{IFF}) was varied between 34.3˚C and 35.3˚C. The indoor temperature of the second floor (T_{ISF}) was changed between 35.8˚C and 36.8˚C.

The monthly average indoor temperature of the ground floor was 33.54˚C. The monthly temperature of the first floor is 34.75 ˚C. The monthly average indoor temperature of the second floor was 36.10˚C. The monthly average of the outdoor temperature was 39.75˚C.

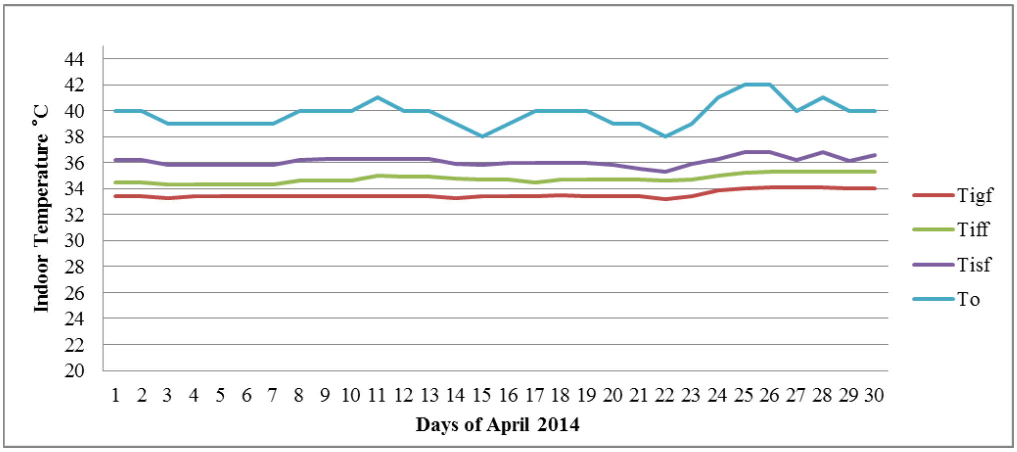


Fig.3 The indoor temperature of the different floors

The indoor temperature of the second floor was more than the first floor. The indoor temperature of the ground floor was less than the second and first floor. The indoor temperature of each the floor was less the outdoor temperature. The Outdoor temperature ranged between 39 ˚C to 42˚C.

4. The Studies of Indoor Temperatures

A common feature noticed from the buildings with high thermal mass was the tendency of similarity between the indoor maximum temperatures and the outdoor air temperature patterns. The author also saw this observation consistently in several studies in California [10] and Israel [11]. It formed the basis for the development of a predictive formula for the expected indoor maximum temperatures, which were described more in 1998 [12]. The equation developed by the author was used to predict for the same type of thermal mass used in this study and, while the patterns look similar, the differences between the predicted and the observed data are consistently about 2–3 ◦C (4–6 ◦F).

The formula developed by Givoni for the prediction of indoor temperatures for the same type of thermal mass was as follows:

$$T_{max\text{-}in} = T_{max\text{-}out} - 0.31(T_{max\text{-}out} - T_{min\text{-}out}) + 1.6 \qquad (1)$$

Where

$T_{max\text{-}in}$ is the indoor maximum temperature;
$T_{max\text{-}out}$ is the outdoor maximum temperature; and
$T_{min\text{-}out}$ is the outdoor minimum temperature.

The formula "refers to continuously cross-ventilated buildings, where the indoor maximum temperature tends to follow closely the outdoor maximum".

The author [13] conducted experiments on closed buildings in Nairobi, Kenya, which is an equatorial high altitude region. Precisely, Nairobi is on latitude 1.3˚S with an altitude of 1798m (5900 ft) above sea level. Thermal mass affects the indoor temperatures in buildings. The author developed a formula on the basis of Givoni to predict indoor maximum temperatures for closed high mass buildings at equatorial high altitudes. It is as follows:

$$T_{max\text{-}in} = T_{max\text{-}out} - 0.488(T_{max\text{-}out} - T_{min\text{-}out}) + 2.44 \qquad (2)$$

Where,

$T_{max\text{-}in}$ is the indoor maximum temperature;
$T_{max\text{-}out}$ the outdoor maximum temperature; and
$T_{min\text{-}out}$ is the outdoor minimum temperature.
The maximum indoor temperature predicted for Chidambaram, by the study of Givoni is Tmax-in =36.99˚C
The maximum indoor temperature predicted for Chidambaram by the study of D.M.Ogoli is Tmax- in = 35.31˚C
The monthly mean indoor temperatures measured for the ground, first and second floors were 33.54˚C, 34.75˚C, 36.10˚C respectively.

There does a difference of 0.89˚C exist between the predicted and the measured values with respect to Givoni study. In the D.M. Ogoli study also there exists a difference of 0.79˚Cbetween the predicted and measured indoor temperature values. These differences found to arise only because of the geographical location and the buildings from the sea level height.

The indoor temperature for a particular place is determined with respect to the outdoor maximum temperature. The indoor temperature predicted for that place is a unique value. Regarding the multi-storey buildings, the number of indoors is equal to the number of stories. A three storey building have three indoors and three indoor temperatures. The indoor temperature of the top floor of the building is found to be closer to the predicted value by Givoni. The other stories have lesser value of indoor temperature than the predicted values.

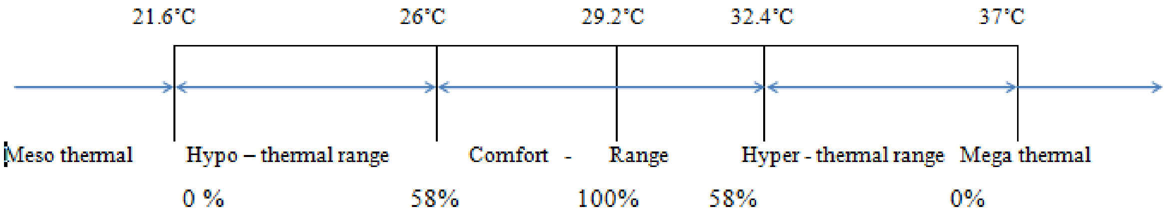
5. Thermal efficiency of the different floors

The indoor temperature determines the quantity of heating or cooling required for the dwelling area. As the indoor temperature increases the electrical energy utilisation also increases. It pushes the house owner to bear a large amount of electric bill. If anybody wants to get thermal comfort in the warm and humid region, he has to spend a lot of money.

The comfort temperature determined by the author in the Hyderabad study[14] is 29.2˚C. The upper and lower limits of comfort temperatures are 32.5˚C and 26˚C. It indicates that those buildings which possess 29.2˚C indoor temperature will be possessing 100% thermal comfort. The buildings having indoor temperature above this will be losing their comfort.

In a recent study, the comfort of the building is zero(null) when the indoor temperaturereaches the human body temperature that is 37 ˚C. 100% to 0% thermal comfort attainment is named as thermal efficiency of the building [15]. Thermal efficiency relates both the indoor temperature and the percentage of comfort.

The linear representation of indoor temperature and the percentage of comfort



0 % 58% 100% 58% 0%
NC CLL C CUL NC
C – Comfort, NC - Null Comfort, CLL – Comfort-Lower Limit, CUL – Comfort-Upper Limit

The upper and lower limits of comfort temperatures are 32.4˚C and 26˚C. The upper and lower limits of indoor temperatures possess only 58% comfort. The comfort range of temperatures 26˚C to 29.2˚C to 32.4˚C provides a comfort of 58% - 100% - 58% for the respective indoor temperatures. If the building is incapable to provide the specified indoor temperature range, that is between 26˚C to 32.4 ˚C the occupant has to use mechanical or electro mechanical instruments for the heating/cooling purpose.

According to this study, thermal efficiency of the ground floor (GF) was 45.0% for the indoor temperature of 33.54 ˚C, thermal efficiency of the First floor (FF) was 29.5% for the indoor temperature of 34.75 ˚C and thermal efficiency of the second floor (SF) was 11.5% for the indoor temperature of 36.10 ˚C.

V. Conclusion

Residential apartments for the cities like Chidambaram, Tamil Nadu with predominant hot and humid climate have the following criteria:

- Roof temperature of all the roofs had a distinct variation. The roof of second floor had a high temperature among the three roofs. The roof of ground floor had a lower temperature than the other two roofs.
- Wall temperature of the different floors showed a variation in their average. Walls of the second floor showed a high temperature than the other walls.
- The indoor temperature of the second, first and ground floor variations are very clear. The indoor temperature gradually decreases from the top floor to the ground floor.

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