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Climate Responsive Planning and Design – A Thermal Comfort Study for Mitigation of Heat Stress

Minakshi Jain, Faiz Ahmed C, Adinarayanane R, Ayon K Tarafdar & Tania Berger

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Contact:
School of Planning and Architecture Vijayawada
Email: adinarayanane@spav.ac.in
Website: www.spav.ac.in

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Abstract: In India, the planning and design of low-income housing has historically been dominated by politics with cost of the unit and quantity being prioritized over quality and comfort. In a country that experiences different climatic conditions throughout the year, buildings need to be responsive to the local climate that helps in improving the thermal comfort of the inhabitants. The need for such intuitive planning and design become even more relevant in places like Vijayawada where the ambient temperature is above 30 degrees for more than half of the year. Further, the thermal environments in the informal sector are often neglected while planning and design of low-income housing settlements. This case study is focused on understanding, mapping and drawing planning & design guidelines for accessing and improving the thermal conditions of New Rajarajeswari Peta -a low-income rehabilitated housing settlement in Vijayawada, a city in India. Archetype characterization of case area was carried out and eighteen archetypes were narrowed down for further documentation and thermal perception study. Documentation of building for recreating virtual models of case houses was carried out through a primary survey. Qualitative interviews on selected cases were performed along with recording thermal sensation votes. Testo-480 and thermal imager camera were used for measuring temperature, humidity, air velocity and iso-thermal images respectively during the course of documentation. DesignBuilder and GIS were used for simulat-ing thermal environment and mapping the case area respectively. The results indicate that as much as three-degree temperature change can be archived by changing the layout, opening sizes, increasing ventilation rate and material properties of these houses, in confirmation with other similar studies (Lau et al., 2019). Further, the perception of heat in low-income housing settlement had varied responses as against the general perception. The findings of the study couldhelp architects, planners and decision makers in making informed design decisions while planning and design of low-income housing settlements.

1 Introduction

In India, the planning and design of low-income housing has historically been dominated by politics with cost of the housing unit and quantity taking being priority over quality and comfort (Marwasta & Nurhidayat, 2019). In a country that experiences different climatic conditions throughout the year, buildings need to be responsive to the local climate for improving the thermal comfort of the inhabitants, particularly in low-income housing settlements (Taleghani, 2018). While frequent heatwaves have become serious issue around the world, especially in India where, compounded effects of high population densities and urban island effects are higher (Baniassadi & Sailor, 2018). In addition, rapid urbanization and the growing socio-economic disparity within city regions, have brought the planning and design of low-income housing areas into limelight (Mahmoud & Gan, 2018; Mohamed Kamar et al., 2019)). Further, the need for such intuitive planning and design become all the more relevant in places like Vijayawada where the ambient temperature is above 30 degrees for more than half of the year. Many studies have highlighted the relationship between the extreme heat conditions and mortality rate (Alessandrini et al., 2019). Further, increase in temperature poses a real risk to the vulnerable population. Despite this, the local government funds construction of many housing schemes to meet the need of the hour without considering the required thermally comfortable environment. Thereby, many such schemes fail to provide the basic level of thermal comfort that is actually required. Further, many studies have observed that due to poor planning of layouts and spatial arrangements, the houses are often observed to be overheated (Ali & Patnaik, 2018; Chen et al., 2018; Nazarian et al., 2019; Wang et al., 2019). Studies in low-income housing settlements across the country show that the majority of the occupants are dissatisfied with the thermal environments and comfort levels provided . Studies from across the globe suggest that the planned future development particularly the planning and design of low-income settlements must address the issues of thermal comfort, wellbeing and energy efficiency (Pomfret & Hashemi, 2017). To address the current and future housing needs and demands, mass housing projects are being planned and constructed. Such mass housing projects must however be planned and designed in a scientific manner so as to achieve the required thermal environments and comfort conditions. In this case study, a low-income housing settlement, New Rajarajeswari Peta in Vijayawada is studied to understand, map and draw planning & design guidelines. These guidelines could then be deployed to access and improve the thermal conditions of a low-income rehabilitated housing settlement in Vijayawada.

2 Thermal Comfort Studies in Low-Income Housing Settlements

Generally, while studying thermal comfort the following five factors are considered, viz., environmental, demographic, social, health, and behavioural factors (Huang et al., 2018, Huang et al., 2019). Although all the five factors influence the thermal perception (Houda et al., 2015; Kajtar et al., 2017; (Xu et al., 2018) and comfort conditions, in this case study environmental factor is studied in detail along with demographic and social factors. It is generally accepted that in order to achieve thermally comfortable indoor environment, four key parameters play vital roles, namely, temperature, humidity, air velocity and mean radiant temperature. In Vijayawada, where the climate is warm-humid, steady and continuous air movement inside the building increases the efficiency of natural ventilation, thereby reducing the discomfort level. This phenomenon is crucial in naturally ventilated buildings and many of the low-income housing settlements are naturally ventilated buildings (Ioannou & Itard, 2017). Although many studies have been carried out to assess the thermal comfort conditions in residential areas in general, focused study on thermal conditions and preferences in low-income settlement is rare (Rincón et al., 2019) .

3 Study Area

Vijayawada is one of the highly populated cities in Andhra Pradesh located in the southern part of India. It is located at a Latitude of 16°31’ North and Longitude of 80°37’ East. As per the census 2011, the population of the city is 10,48,000 (Census, 2011). The case study is performed in New Rajarajeswari Peta, a rehabilitated low-income housing settlement in Vijayawada, India. The case area is identified for understanding, mapping and drawing planning & design guidelines for improving the thermal conditions.

4 Data and Methods

In order to understand the thermal environment, sensation and comfort, a number of procedures were followed for mapping, modelling and interpretation.

4.1 Case Area Selection

Out of the 110 notified slums, New Rajarajeswari Peta is one of the rehabilitated low-income housing settlements. Based on the secondary data analysis on population, conditions of slums, accessibility and availability of GIS data with the municipal corporation in Vijayawada, four case areas were identified. Further, all the four case areas were visited to gather first-hand information and finalize the selected case area. Based on the availability of data, organized layouts, and accessibility New Rajarajeswari Peta was finally selected for further studies.

4.2 New Rajarajeswari Peta

New Rajarajeswari Peta is one of the rehabilitation housing schemes constructed in early 2000s. The total site area extent is 900m x 1200m approximately. Two distinct housing schemes have been executed in New Rajarajeswari Peta. First, row housing with plot size ranging from 40 sq.m to 60 sq.m and second, densely packed apartments. Based on the reconnaissance survey, a part of New Rajarajeswari Peta layout was identified to create GIS based database for further analysis.

4.3 Archetype Characterization

Within the identified case area, there are more than hundred individual housing units and thirty-three apartments (with thirty-two units in each of the apartment) that can be studied. However, not all the housing units within the case area were documented and studied. A representative sample of housing units from individual housing and apartments were derived using archetype characterization for documentation, conducting surveys and field measurements. A detailed methodology as developed by Ali et al., (2019) and Cerezo et al., (2017) is used in this case study for archetype characterization of study area and identification of specific case buildings for further study.

4.3.1 Archetype Individual Housing Units

For generating archetype for individual housing units, parameters such as immediate context (adjacent building heights), number of floors, orientation and construction material (material finishes of walls and roofs) were used. Based on the permutation and combination, eighteen individual housing units were derived for detailed documentation and further study. In this report, documentation of two individual houisngs units are shown, Figure 1 and Figure 2.

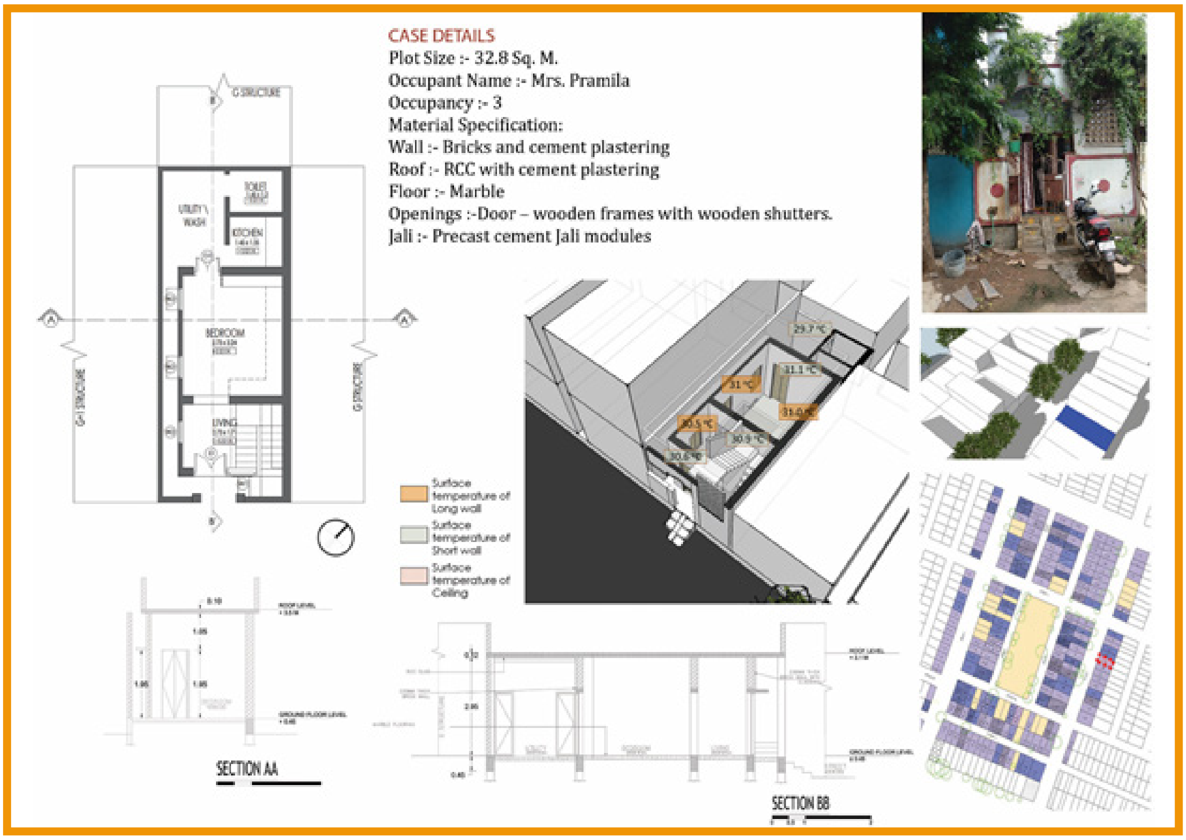

Figure 1. Documentation case house ID No. 2 - Archetype

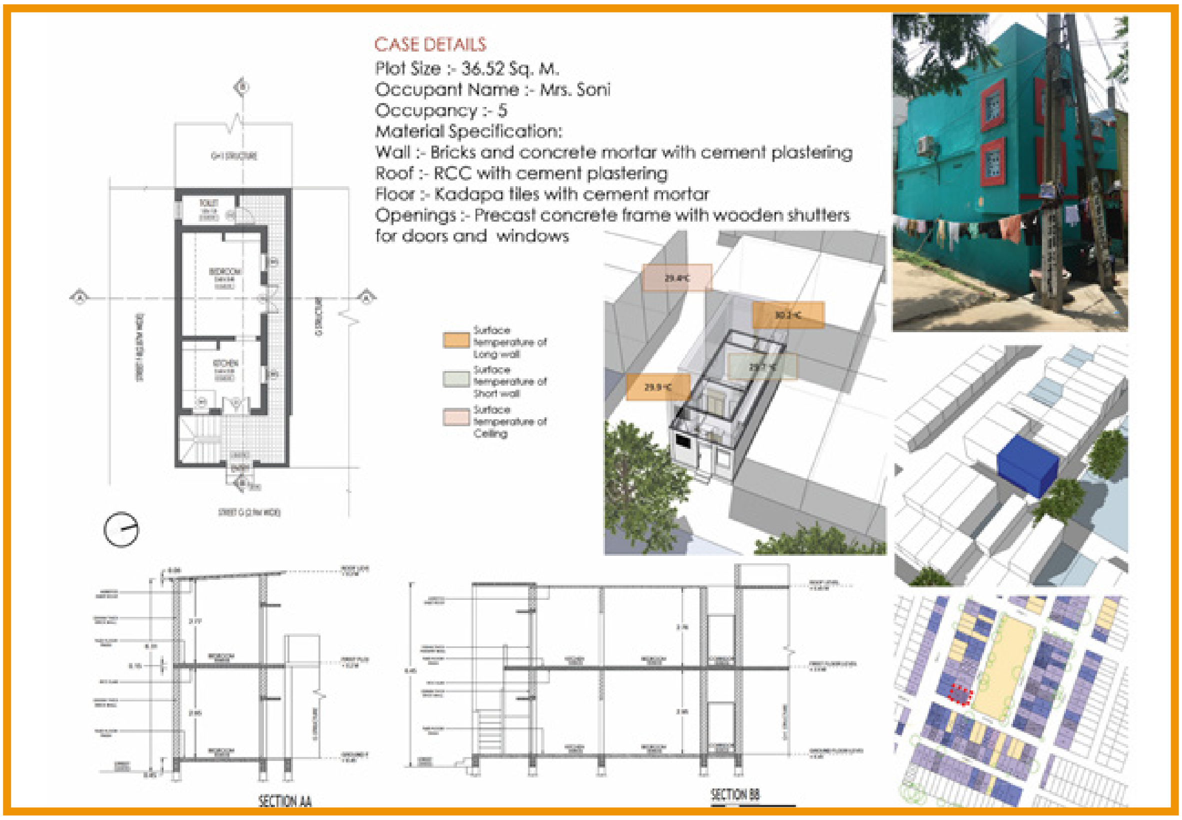

Figure 2. Documentation case house ID No. 3 - Archetype

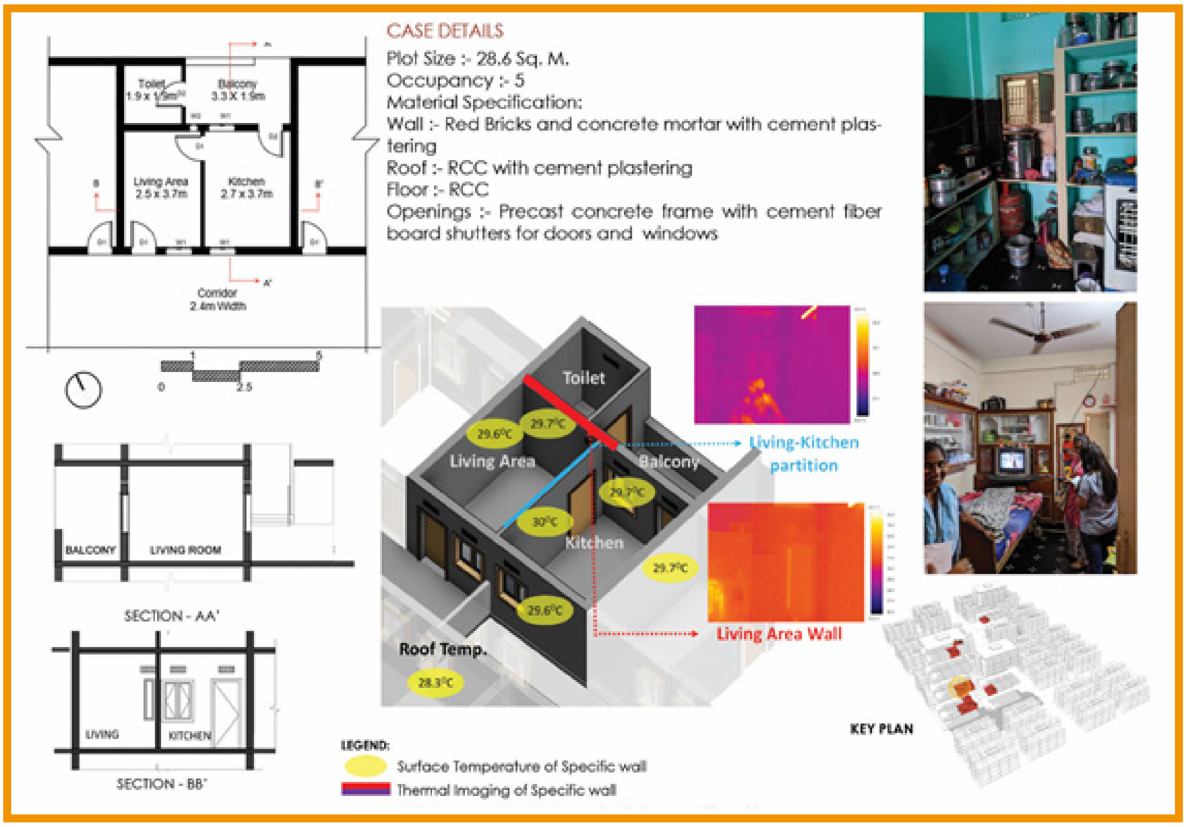

Figure 3 Documentation case house ID No. 20 Apartment (intermediate Unit) - Archetype

4.3.2 Archetype Apartment units

For generating archetype for apartment units, parameters such as orientation, units in lower-most and upper-most floors, units exposed to two side roads, units exposed to single side road and units which are sandwiched between two units were used. Based on the permutation and combination, six units were derived for detailed documentation and further study. In this report, documentation of one of the apartment's intermediate unit is shown, Figure 3.

4.4 Three-Dimensional Models of Archetypes

Based on the archetype, a detailed three-dimensional model of individual and apartment housing units was modelled and the same was validated by physical verification at the respective units. Care was taken to model all the contextual elements such as adjacent buildings, vegetations, or any obstructions in and around the identified archetype. Further, a detailed material mapping was carried out to make the models close to reality.

4.5 Qualitative Interviews

During July 2019, six indepth qualitative interviews were conducted within the identified archetype housing units both in the individual and apartment units. Semi structured qualitative questionnaires were prepared to carryout the interviews. Interviews were translated and transcribed from Telugu into English by local translators. An extensive research diary filled in during field trips to conduct interviews allowed for continuous reflection on topics raised and recording observations. Throughout the course of the research this allowed for adaptation and fine tuning of the investigative approach. Answers provided by interviewees were attributed to questions and inserted into a matrix to allow for overview both across different interviews and topics touched by each interview. Cross readings in both dimensions brought clusters of relevant points to the fore, which are presented hereafter. Interviews were conducted based on the following research question:

How is heat perceived? When is it perceived as a burden?

What remedies are applied to reduce negative impacts of heat? How effective are these? How do people know about these remedies?

How do buildings contribute to reducing negative impacts of heat?

Which is microclimate's influence on (perception of) heat?

The following hypotheses were established before and tested in the interviews. Hypotheses formulated at the onset of research represent the state of knowledge at that point and comprised the following:

Due to their socialization, people have learned how to deal with heat (coping strategies).

During increasing intense heat waves (both in terms of absolute temperatures and duration) traditional coping strategies are reaching their limits

4.6 Thermal Sensation Survey

In addition to the qualitative interviews performed with the inhabitants at selected units, thermal sensation survey was performed in all the archetypes of individual and apartment units. This thermal sensation survey was developed based on Ashrae 55 thermal comfort standards. The survey was intended to record the following six components namely,

Background information of the respondents: This included the age, gender, education, living history for understanding the acclimatization the respondents.

Thermal conditioning and radiant objects: Visual survey documentation was carried out to map the major elements that add to the radiant environment and also help in regulating the thermal conditions such as fan/AC etc.

Thermal environment assessment: air temperature, air velocity and humidity were recorded simultaneous when the thermal perception survey was carried out.

Thermal Sensation Vote: In a standard format, the thermal perception at the time of survey was recorded.

Activity Mapping: In addition to the above, activity of the occupants was mapped to understand the overall functioning of the units. Thermal Senstaiton Vote: In a standard format, the thermal perception at the time of survey wasrecorded.

Activity Mapping: In addition to the above, activity of the occupants was mapped to understand the overall functioning of the units.

4.7 Field Measurements

Using Testo-480 and thermal imager camera temperature, humidity, air velocity and iso-thermal images were respectively recorded and mapped, for 01 August 2019, following the due protocal (Benton et al., 2020, Johansson et al., 2014). These measured data were used for validating the simulated results from DesignBuilder software. An extrapolated TMY file of Vijayawada from Meteonorm was used as weather file for simulation.

4.8 Modeling and Simulation

GIS was used extensively to create database of the existing housing settlements. This database would further be used in analysing the layout at macro-scale. Further, DesignBuilder was used for simulating the air temperature, humidity, air changes, and heat influxes. Standard input data template set were created using conventional wall and roofing material for creating base case Further, iterations were generated by changing the critical parameters such as spatial organization of the spaces (internal layout), introduction of simple passive strategies, change of roof profile, opening sizes, and roof & wall materials along with their finishes.

5 Analysis and Findings

The dataset populated and generated during the course of the case study were analysed in three stages.

5.1 Building Performace Analysis

The foremost analysis carried out on the dataset collected is through simulation. For this purpose, virtual building model was created in DesignBuilder software. Base case simulations were carried out by keeping using conventional wall material i.e. Burnt clay brick of 100x100x200 mm thickness, with 25 percent of the total plot area were kept open as per the byelaws. Roof were made of RCC 100mm with no weather proofing material. Occupant ratio considered were 0.16 people/meter square (i.e. with five-person occupancy). The annual hourly data was simulated using the above data input, and relative humidity (RH), air temperature (AT), radiant temperature (MRT), operative temperature (OT) and outside dry-bulb temperature (DBT) were extracted. 18 cases were simulated for comparative analysis and drawing comphrensive conclusions. In this report, results of the three cases are discussed which are as follows. The hourly annual simulated data of Case ID no. 2 is shown in Figure 4. The average outside DBT simulated is 28.1 degree celcius whereas the average MRT inside the house is 30.4 degree celcius, , further the average hourly MRT inside during the peak summer months (April-June) is 33.1 degree celcius. The average MRT measured within the units on 1st of August 2019, was 31.1 degree celcius at 17:00 hours. Negligible air speed of 0.03m/sec was recorded during the same time.

The hourly annual simulated data of Case ID

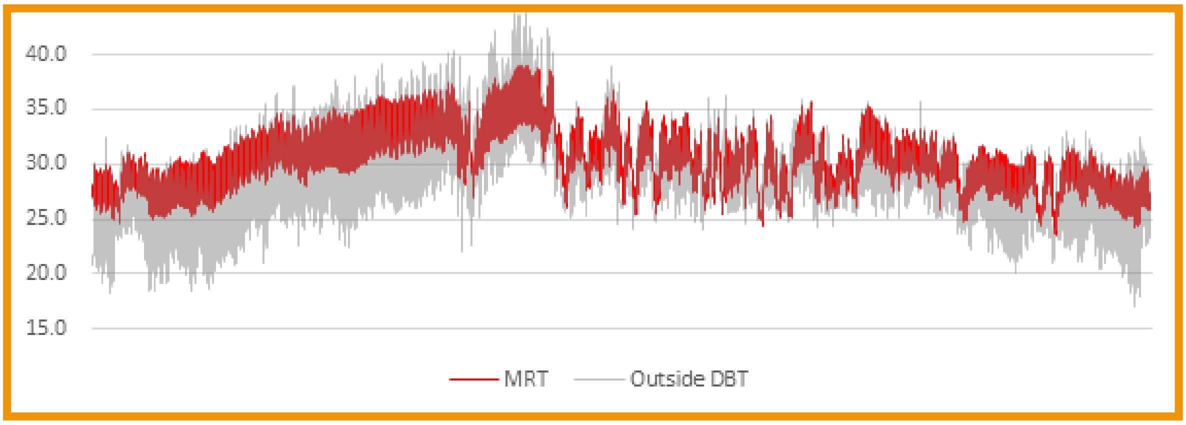

Figure 4. Annual simulated hourly DBT (Outside) and MRT (inside) for an individual ground structure (case house ID No. 2)

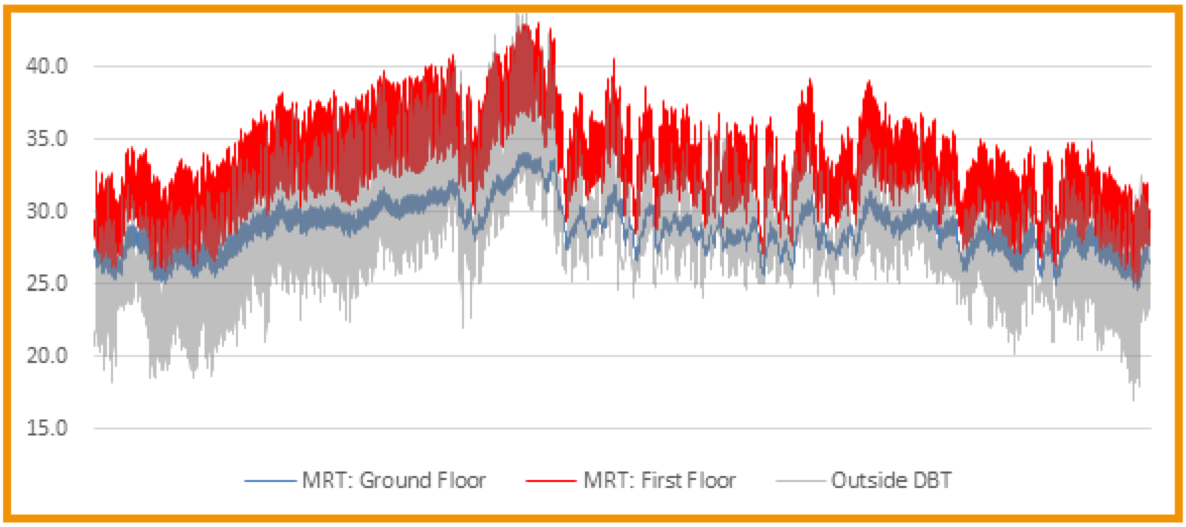

Figure 5 Annual simulated hourly DBT (Outside) and MRT (inside) for an ground and first floor structure (case house ID No. 3)

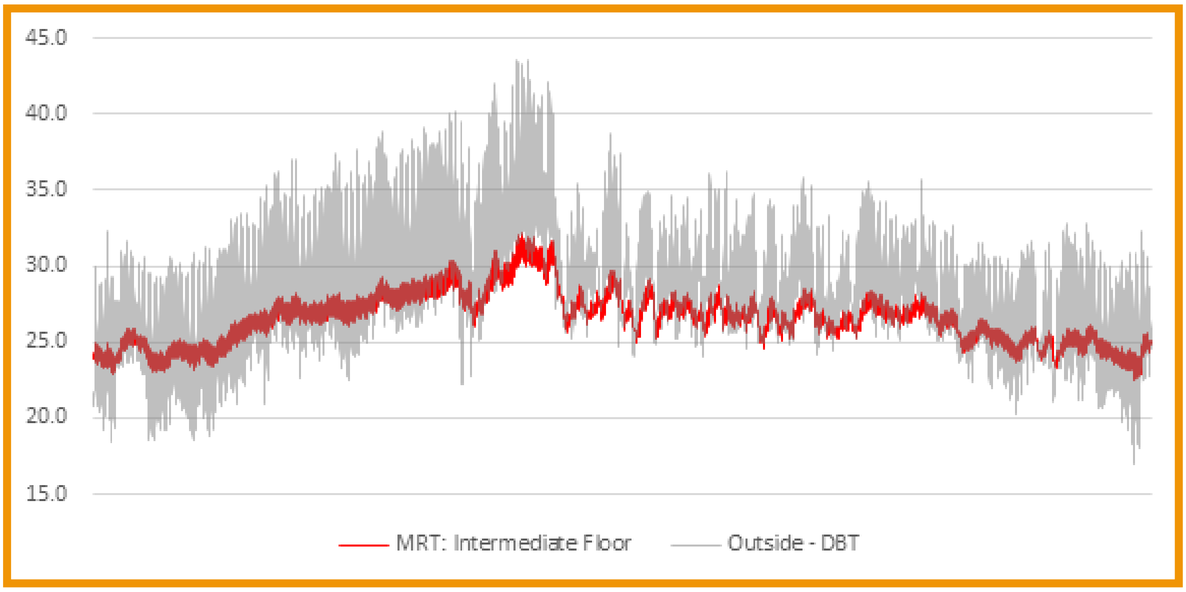

Figure 6 Annual simulated hourly DBT (Outside) and MRT (inside) for an apartment interme-diate structure (Case ID no. 20 apartment Unit)

no. 3 is shown in Figure 5. The average outside DBT simulated is 28.1 degree celcius whereas the average MRT inside the house is 28.8 and 32.9 degree celcius in ground and first floor respectively. Further the average hourly MRT inside during the peak summer months (April-June) in ground and first floor is 30.7 and 36 degree celcius respectively. The average MRT measured within the units on 1st of August 2019, was 29.7 degree celcius at 15:30 hours. Negligible air speed of 0.09m/sec was recorded during the same time.

The hourly annual simulated data of Case ID no. 20 (apartment Unit) is shown in the Figure 6. The average outside DBT simulated is 28.1 degree celcius whereas the average MRT inside the intermediate apartment unit is 26.6 degree celcius, further the average hourly MRT inside during the peak summer months (April-June) is 28.5 degree celcius. The average MRT measured within the units on 30th of July 2019, was 30.7 degree celcius at 15:50 hours. Negligible air speed of 0.03m/sec was recorded during the same time. From the Figure 6, it is also evident that first floor MRT is way higher than outside DBT throught the year, indicating higher discomfort in the upper floors, as the terrace is directly exposed to sun.

Interesting, the results indicate that inside MRT is relative higher that outside temperature DBT throughout the year as shown in the figures. The inside MRT is much higher than the outside DBT clearly indicates that the thermal environment inside the house is not comfortable. Further, similar analysis are carried out for the all the eighteen case studies both individual and apartment units, the results are in the similar partern, i.e. MRT is higher than the ambient air temperature, throughout the year creating prolonged discomfort period. These prolonged discomfort period directly and indirectly affects the ouccpant wellbeing which requires immediate actions for retrofitting and the lessons learnt here can help in drawing planning and design guidelines for new projects elsewhere.

5.2 Interpretation of qualitative interviews

Hypothesis A

"Due to their socialization, people have learned how to deal with heat (= coping strategies)"

A recurring statement of interviewees went like this: "we don't bother about heat, we are used to it". This indicates that heat tolerance functions as coping strategy (> hypothesis 4). Other coping strategies often mentioned include: drinking more (water, buttermilk etc.), covering one's head in direct sunlight, wetting curtains and other textiles. . Questioned about how/ from which source they know about these remedies, most interviewees referred to socialization by indicating that they had seen their mothers and grandmothers doing so or that this "was simply in our blood" (which is interpreted to be synonymous for tacit knowledge).

Hypothesis B

"During increasingly intense heat waves (both in terms of absolute temperatures and duration) traditional coping strategies are reaching their limits"

It proved difficult to make a reliable statement on hypothesis B as this turned out to be formulated in an imprecise manner;

1) It assumed increasing intensity of heat waves. Such an increase, however, was not confirmed by all respondents. Most of them though agreed that heat was "getting more and more" during the last years. But this

confirmation remained somewhat generic and little convincing in most cases, rather like an assertion to a general feeling that “everything was better in the past”. This impression was fueled by the brevity of answers provided as well as by the fact that they were rather uniform and superficial. Most respondents specifically referred to the last few years and stated increases in heat for this period. Only when asked explicitly, whether they expected temperatures to raise further in the future and whether they were fearful of such development, most would agree that they did while some expressed no such fears. A few interviewees mentioned – in this context or another – that they were aware of media news on heat related deaths in the country and many, though not all, indicated that they had heard about climate change. In some cases, interviewees linked increased temperature to traffic and air pollution (as well as cutting of trees in their neighborhood). While people’s perception on temperature increase is mixed, it is difficult to provide an objective picture on the matter.

2) Hypothesis B implicitly assumed that there are definable limits to coping strategies. However, it was not defined beforehand how such limits would manifest themselves, which would be the consequences of reaching them. Based on interview findings, this could be narrowed down to the following understanding: a coping strategy reaches its limit when people stop applying it because they perceive it not to work any longer under the given circumstances. This can also be the case if the strategy in question, though still effective in principle, needs to be applied with increased frequency in order to effectuate relief in terms of thermal comfort. At a certain point in time, the effort required to apply the strategy time wise or money wise is not regarded as being worthwhile any more when set into relation with the effects it achieves. Another example concerns the coverage of roofs with grass or (palm) leafs: it was given up, besides other reasons, because it tried out rapidly, thereby loosing effectivity (Interview 4 – 2.2, Vijayawada).

3) Additionally, it would be necessary to verify if at all coping strategies mentioned by the interviewees could possibly be effective in physical or physiological terms. Strategies, which do not yield any positive effect on indoor temperature or physiological parameters of residents may still be used as such but their effectiveness stems from people’s subjective perception rather than real effects. In the case of grass or leafs spread on buildings’ roofs a certain insulating effect can be suspected, but it is difficult to accurately assess it as reliable heat transfer coefficients [K/m2H] for loosely applied such substances are hard to come by (especially as air circulation within this material is not restricted and thus the insulating effect of air can only partially be harnessed). In the case of wet curtains, cooling effects of evaporating moisture is well researched, but detailed thermal simulation would be necessary to assess the actual effect under the different circumstances in interviewees’ homes.

In conclusion, hypothesis B is hard to either verify or falsify; Respondents’ answers rather point to a general perception of increased heat during the last years, but this signal is blurred.

In the interviews, some examples of coping strategies were found, which were given up due to decreased effectiveness. It appears at least plausible that these strategies indeed had less impact in terms of indoor temperature and human physiology under higher outdoor temperatures.

6 Conclusion

In this case study, thermal comfort comparative assessment of eighteen housing units in low income housing area of Vijayawada was carried out, of which three cases are presented in comprehensive nature. A detailed methodology was developed which can be applied to other case studies else where. Thisincludes criteria for selection of case area, housing unit identification for performing thermal pception and performance assessment using Archtype, field measurements and standard thermal perception survey format, and qualitative indepth interviews etc. The results of the case studies indicate both through subjective and objective anlaysis, the comfort conditions within the living units are poor, immediate actions are required for improving the thermal conditions of living spaces. Further, through experimentation, it is found that as much as three-degree temperature change can be archived by changing the layout, opening sizes, increasing ventilation rate and material properties of these houses, which indicates that guidelines for improving planning and design of these layouts and units can be taken it up in the form of retrofitting or during new planning and development of layout. Further, the perception of heat in low-income housing settlement had varied response as against the general perception, i.e. woman respondents seems to be more resilient by nature than their counter parts. The findings of the study could further help architects, planners and decision makers in making informed design decisions while planning and designing of low-income housing settlements.

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