International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 09, Special Issue | Feb 2022 www.irjet.net p-ISSN: 2395-0072

"Metagreen Dimensions, 2020 - 2nd International Conference on Performance of Built Environment
Organised by: College of Architecture Trivandrum, INDIA"

Indoor Environmental Evaluation of Traditional and Contemporary Mud Houses in Kerala

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***ABSTRACT**: Indoor Environmental Quality (IEQ) has a direct influence on human health and productivity, and it is one of the indicators of social sustainability. According to the National Human Activity Pattern Survey (NHAPS) published in 2001 and the European Environment Agency (EEA) Report published in 2013, people spend almost 90% of their time indoors. Therefore, it is very much relevant to investigate the IEQ of buildings and suggest measures to reduce the negative impact on human health and productivity. This study aims to investigate the IEQ of earthen buildings. Earthen buildings are often considered as an epitome of sustainable construction. Even though the materials used and construction techniques employed changed over time, Kerala has a rich tradition in earthen construction. This study focuses on analyzing earthen construction as an efficient indoor comfort technique. One traditional and one contemporary mud house located in Calicut district were evaluated. The investigations were carried out with the aid of instruments for measuring temperature, humidity and air velocity along with a questionnaire survey to record the comfort of occupants. The thermal comfort and daylighting comfort were evaluated in both the buildings and analyzed using CBE thermal comfort tool and manual daylighting method, respectively. The results were compared with standards to draw meaningful conclusions. The research outcome would reinforce the merits of earthen buildings towards IEQ and helps in improving the comfort, well-being, and productivity of occupants.*

KEYWORDS: Indoor environmental quality, Thermal comfort, Daylighting, Earthen buildings, Mud houses

1. INTRODUCTION

Buildings account for almost 50% of the global electricity use, including both residential and commercial buildings(IEA, 2018). The residential sector itself consumes 27 % of the world's total electricity consumption(IEA, 2018). The national statistics also show that the residential sector consumes a considerable amount of electricity, which accounts for almost 24%(CEA-Ministry of Power-Government of India, 2017). Lighting and cooling requirements together account for almost 70% of the electricity consumption in the residential sector. Natural lighting and passive cooling techniques help in reducing the electricity consumption and also enhance the Indoor Environmental Quality (IEQ) of residential buildings. Thermal comfort of occupants and availability of daylighting greatly influences the IEQ of a space. The materials and construction techniques employed has a major role in achieving IEQ. Indoor Environmental Quality has a direct influence on human health and productivity, and it is one of the indicators of social sustainability. This study aims to investigate the IEQ of earthen buildings. Earthen buildings are often considered as an epitome of sustainable construction and are expected to meet the increasingly demanding standards of sustainability. Therefore, this study is an attempt to evaluate the IEQ of earthen buildings. Even though IEQ is defined by several other factors, this study is limited to thermal comfort analysis and daylight analysis along with a questionnaire survey.

Two mud houses, one traditional residence and one contemporary residence from Calicut, Kerala were selected for the study. The temperature, humidity and air velocity were recorded for both the residences and the thermal comfort analysis were done using the CBE thermal comfort tool. The details of openings were also collected and daylighting analysis was done using the manual daylighting compliance method described in the Energy Conservation Building Code (ECBC). Moreover, a questionnaire survey was conducted among the occupants to record their overall satisfaction on indoor comfort. The results were compared with standards to draw meaningful conclusions. The research outcome would reinforce the merits of earthen buildings towards IEQ and helps in improving the comfort, well-being, and productivity of occupants.

The paper is organized into six sections. The first section gives a brief introduction to the need for conducting the study. The second section illustrates the detailed steps followed in the current study with the help of a methodology flowchart. The third section explains in detail the tools, techniques and instruments used in the study. The fourth section presents the results of the study. The fifth section provides a detailed discussion based on the results obtained and the last section ends with conclusions.

2. RESEARCH METHODS

2.1. Detailed methodology

The study starts with the selection of the case studies. One traditional and one contemporary mud house located at Calicut Kerala was selected. The entire study is divided into three parts: 1) Thermal comfort analysis; 2) Daylighting analysis; 3) Occupant satisfaction survey. The investigation was conducted during the summer season. The detailed methodology is illustrated in Figure 1.

In the first part of the study, thermal comfort parameters like air temperature, humidity and air velocity of each room are measured. Five samples

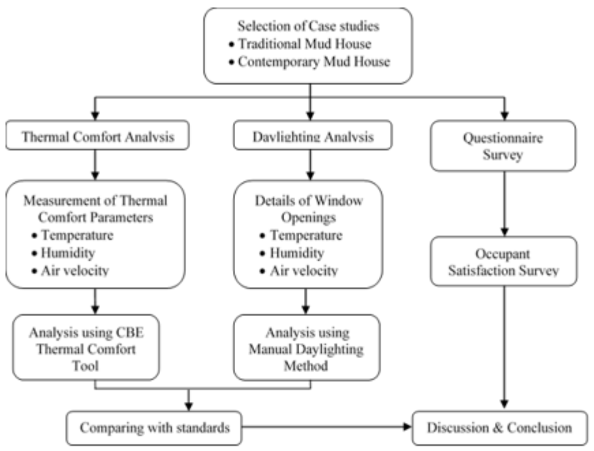

Figure 1: Methodology Flowchart

were taken in each room at each 1-hour time interval from 10 am to 6 pm. The measurements were taken at a level of 1.5 m from the floor. The thermal comfort analysis is performed using the CBE thermal comfort tool(Tyler, Stefano, Alberto, Dustin, & Kyle, 2013). This method has been employed in thermal comfort study conducted by Visakha et al.(Visakha, 2014; Visakha, Lazar, & Chithra, 2017) and Naseer et al.(Naseer & Joshima, 2018). In the second part of the study, the details regarding the window openings like the sill height, width and height of the opening, the width of the shading and the orientation of the opening were recorded. The daylighting analysis was performed using the manual daylighting compliance method, as mentioned in the ECBC(Bureau of Energy Efficiency, Ministry of Power, 2017). The results of thermal comfort analysis and daylighting analysis were compared with standards to draw meaningful conclusions. In the third part of the study, a questionnaire survey was conducted among the occupants to directly record their comfort level. Occupant satisfaction is identified as an important factor in evaluating performance of buildings along with direct measurement of thermal parameters(Abbaszadeh, Zagreus, Lehrer, & Huizenga, 2006; Paul & Taylor, 2008) Further, the results are discussed in detail, and the study ends with conclusions.

2.2. Case study details

The traditional case study selected is a 500-year-old courtyard house with a built-up area of 124 sqm and facing the southwest direction. The building

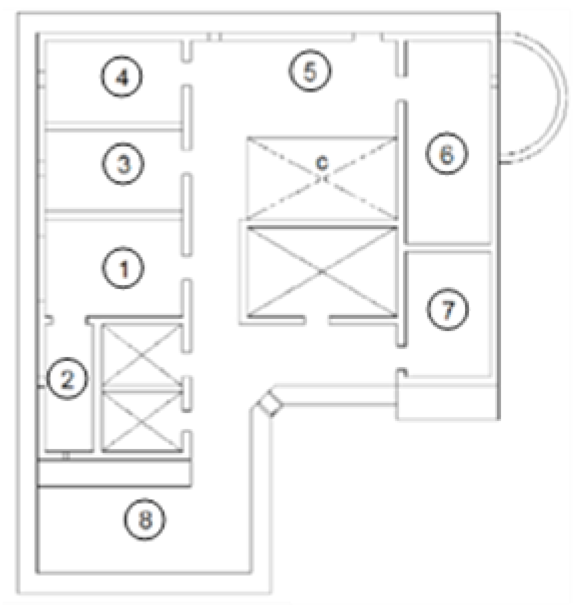

Figure 2: Layout of Traditional Residence

envelope is made up of mud blocks along with lime mortar and plastered with lime and mud. The roof is framed with timber and thatched in three layers using natural straw, coconut leaves and palm leaves. The building consists of 7 rooms and a verandah. The building layout is shown in Figure 2.

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Figure 3: Layout of Contemporary Residence

The contemporary case study selected was constructed in 2013 with a built-up area of 217 sqm. The building is constructed using Compressed Stabilized Earth Blocks (CSEB) and laterite. A combination of mud, lime, sand is used for plastering the surfaces. The roof is structure is formed using steel sections and terracotta tiles are laid over it. The building has a greater number of windows and skylight. The materials and other design elements are used sensibly all of them synchronize with the whole. The building consists of 7 rooms on the ground floor and three rooms on the first floor. The building layout is shown in Figure 3.

3. TOOLS AND TECHNIQUES EMPLOYED

3.1. CBE thermal comfort tool

Centre for Built Environment (CBE) Thermal Comfort Tool is a web-based tool developed at the University of California at Berkeley for thermal comfort calculations according to ASHRAE Standard 55-2013. This is a free online tool that allows designers and other practitioners to perform thermal comfort calculations. Figure 4: The interface of CBE Thermal Comfort ToolFigure 4shows the interface of the CBE thermal comfort tool. The tool has three main parts: Left section is the user interface. It contains the input fields. The top-right section contains the results of the calculations. The bottom-right section contains a visualization of the thermal comfort conditions (Tyler et al., 2013).

The PMV method is adopted for thermal comfort analysis. Using this tool, the thermal comfort level of a space can be understood based on PMV and PPD values and from the graph plotted. Environmental parameters like Dry Bulb Temperature (DBT), Wet Bulb Temperature (WBT), wind velocity, and personal parameters like metabolic rate and clothing level. The first three parameters indicate the condition of the room, which is plotted in red. The last three parameters define the comfort zone plotted in blue.

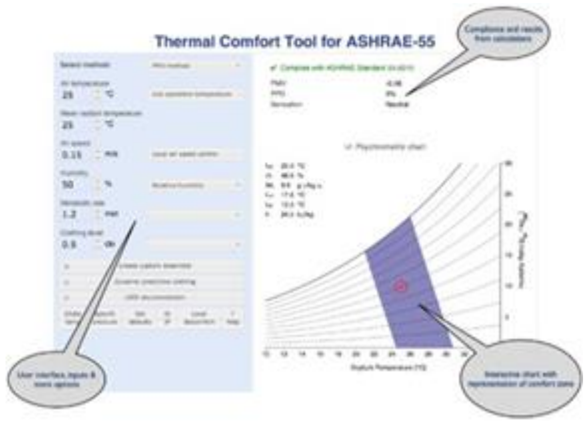


Figure 4: The interface of CBE Thermal Comfort Tool

When the two regions overlap, the graph represents comfort condition, and the PMV value will be between -0.5 to +0.5. The thermal comfort parameters like temperature, humidity and air velocity are measured using thermometer, hygrometer and anemometer, respectively. The clothing level is assumed as 0.5 clo and metabolic rate as 1.1 met.

3.2. Manual daylighting compliance method

Manual daylighting compliance method is used for showing compliance with the requirements of daylighting without simulation. Daylight extent factors (DEF) stated in Table 4-3 of ECBC 2017 is used for calculating the percentage of floor area meeting the Useful Daylight Illuminance (UDI) requirement for 90% of the potential daylit time in a year. The DEF depends on the projection factor (PF), latitude, window type, Visual light transmittance (VLT) and orientation. After determining the DEF, the daylit area is calculated. Multiply DEF by the head height of the opening or till an obstruction higher than the head height of the fenestration, whichever is less to calculate the daylit area in a direction perpendicular to the opening (denoted by Y). In the direction parallel to the opening, the daylit area extends to a horizontal distance equal to the width of the opening plus either 1 meter on each side of the opening, or the distance to an obstruction, or one-half the distance to an adjacent opening, whichever is least (denoted by X). The total daylit area (A) is given by the Equation (1) given below

$$A = X * Y \quad (1)$$

The calculated daylit area is further compared with the requirements given in Table 4-1 of ECBC 2017.

3.3. Questionnaire survey

The questionnaire was adopted from Indoor Environmental Quality Standard-ISHRAE 10001 2016(ISHRAE, 2016). It comprises of ten questions to be rated in the 7-point scale where rank 1 stands for very dissatisfied and rank seven stands for very satisfied.

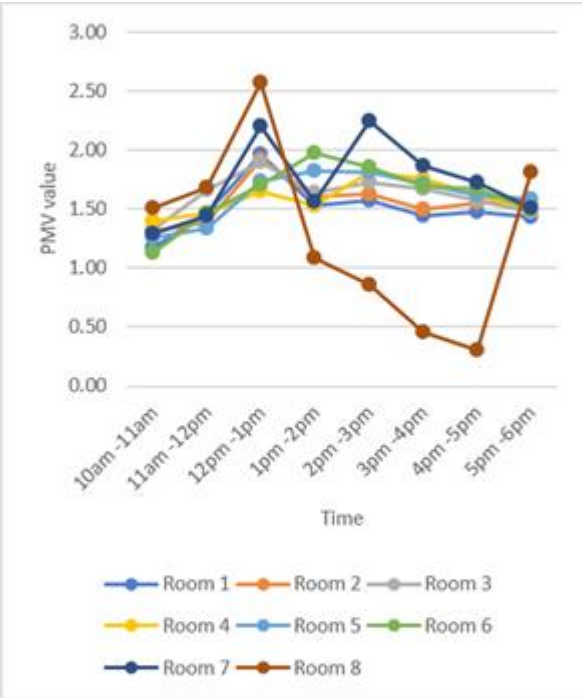
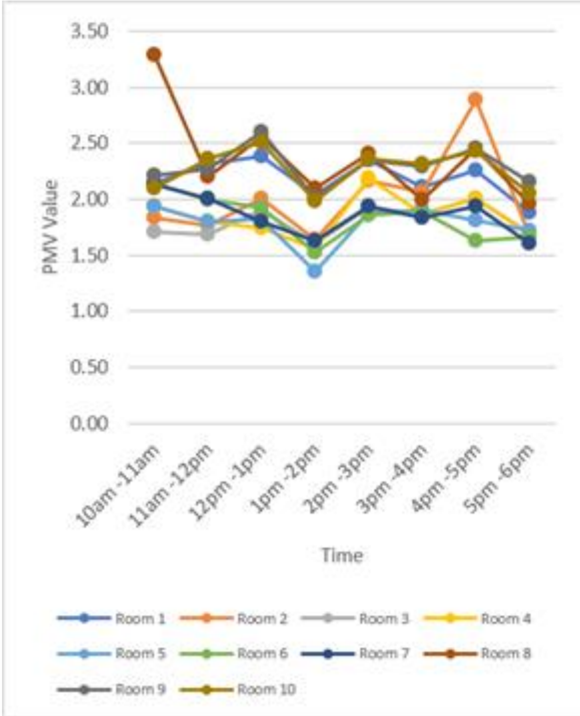


Figure 5: PMV value of traditional residence

While conducting the questionnaire survey, more factors influencing IEQ were considered apart from thermal comfort and daylighting. The questionnaire was administered among the occupants, 4 in each case study. Ten questions were asked regarding occupant satisfaction on indoor comfort, which includes temperature in different season, humidity, air movement, air quality, noise, daylight, external view from building, etc.

Figure 6: PMV value of contemporary residence



4. RESULTS

4.1. Thermal comfort analysis

The PMV values for both the traditional residence and the contemporary residence are calculated using CBE thermal comfort tool. It is shown in Figure 5and Figure 6, respectively.

ROOM NO	TOTAL ROOM AREA IN SQM	DAYLIT AREA IN SQM
ROOM 1	8.16	5.19
ROOM 2	3.78	0.95
ROOM 3	6.80	2.60
ROOM 4	12.24	2.60
ROOM 5	10.50	2.90
ROOM 6	6.30	0.85
TOTAL AREA	47.78	15.08
	AREA %	31.56%

Table 1: Daylit area calculation of traditional residence

ROOM NO	TOTAL ROOM AREA IN SQM	DAYLIT AREA IN SQM
ROOM 1	19.69	18.83
ROOM 2	12.30	11.07
ROOM 3	12.33	6.14
ROOM 4	12.71	12.71
ROOM 5	11.72	10.59
ROOM 6	5.40	5.40
ROOM 7	2.96	1.17
ROOM 8	12.30	12.30
ROOM 9	9.30	9.30
ROOM 10	12.71	10.68
TOTAL	111.42	98.19
	AREA %	88.12%

Table 2: Daylit area calculation of contemporary residence

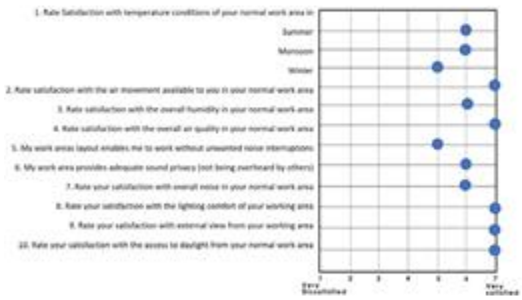


Figure 7: Questionnaire Survey Results for Traditional residence

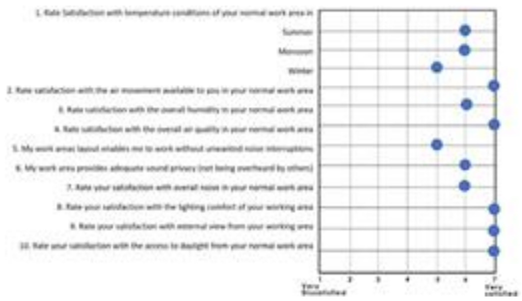


Figure 8: Questionnaire Survey Results for Contemporary Residence

4.2 Daylighting analysis

The daylit area for both traditional residence and contemporary residence is calculated and is shown Table 1: Daylit area calculation of traditional residencein Table 1 and Table 2, respectively.

4.3 Questionnaire survey

The questionnaire survey results for both traditional residence and contemporary residence is shown in Figure 7 and Figure 8, respectively.

5. DISCUSSION

The average outdoor temperature was recorded as 36^{0}C, and the highest outdoor temperature was 43.5^{0}C. The lowest temperature observed in the case of traditional residence was 28.2^{0}C between 10 am and 11 am. PMV value above 2.5 was obtained for verandah during the forenoon, whereas showed the lowest PMV value during the afternoon due to high wind speed, approximately 2.4 m/s to 4 m/s. Most of the PMV values range between +1 and +2, indicating slightly hot condition inside. The lowest temperature observed in the case of the contemporary building was 28.55^{0}C between 10 am and 11 am. Most of the PMV values range between +1.5 and +2.5, indicating hot condition inside. The indoor thermal comfort condition inside both the buildings could be enhanced by considering an air velocity of 0.3 m/s corresponding to the wind speed of the fan.

The total daylit area in case of traditional residence is 31.56%, which is below the threshold 45% (the threshold for resorts is considered since residential buildings are not covered under ECBC). Small openings resulted in the low percentage of daylit area. Generally, the opening in traditional residences was small, considering the traditional lifestyle and privacy factor. The total daylit area in the case of contemporary residence is 88.12%. The presence of large windows and skylight helps in achieving high % of the daylit area. Use of white colour inside the building also helps in improving lighting. The courtyard space also helps in enhancing the daylighting inside.

The minimum and maximum values from the questionnaire survey is shown in Figure 7 indicates that the overall comfort of the occupants in traditional residence is satisfactory. All the values are equal to 4 or above 4, the neutral condition. The

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questionnaire survey results show that the traditional residence is comfortable. The minimum and maximum value of the survey results shown in Figure 8 indicates that the overall comfort of the occupants in contemporary residence is satisfactory. All the values are above 4, the neutral condition. The questionnaire survey results show that contemporary residence is comfortable.

6. CONCLUSION

The current study involves the thermal comfort analysis and daylight analysis of two mud houses constructed in two different periods. Both the buildings have incorporated passive techniques like courtyards, openings for cross ventilation, shading etc. The thermal comfort analysis using CBE thermal comfort tool indicates that both the buildings require some mechanical ventilation systems like fan or exhaust systems to attain the comfortable condition in the peak summer season. From the daylighting analysis, it was clear that the daylighting in traditional residence is low due to small windows, whereas the daylighting in contemporary residence is higher accounted by the provision of large openings and skylight. The questionnaire survey conducted among occupants indicates that the occupants in both the buildings enjoy satisfaction regarding thermal comfort, daylighting and noise. The study adds to the fact that the earthen buildings are a sustainable way of construction with low environmental impact. Earthen construction might help in achieving thermal comfort condition inside the buildings with minimum energy consumption.

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