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Climatic Investigation of a Contemporary Church in Kochi for Thermal Comfort

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ABSTRACT: Thermal comfort studies correlate the comfort of occupants in a built environment to the functioning and energy utilization of a building. Many thermal comfort studies have been carried out in buildings that are occupied for the major portion of a day such as classrooms, offices, etc. Whereas the number of studies carried out in building typologies such as mosques, churches, etc. which are not occupied for more than four hours per day, are not many. This study was intended to analyse the thermal comfort of occupants of a contemporary church in warm- humid climate. A recently constructed naturally ventilated church, having a regular occupancy of over 1,000 people in Kochi, Kerala, was identified as an ideal case to study various climatic parameters affecting thermal comfort. The environmental factors affecting thermal comfort have been studied through field measurements and occupant satisfaction surveys. The study was carried out step by step including climate study for climate analysis, in-situ survey for short time representative quantitative evaluation and building simulation tools for a whole year quantitative evaluation. The simulation model was validated with qualitative and quantitative data to verify that the theoretical and actual data are correlating. From the study, it was observed that for a certain duration, there was a period of discomfort amongst the occupants. The probable causes for this discomfort have been discussed This research was an attempt to give an understanding of the patterns of occupant thermal comfort in a space intended for a brief duration of occupancy

KEYWORDS: Thermal Comfort, Warm-Humid Climate, Bioclimatic Strategies, Naturally Ventilated

1. INTRODUCTION

Buildings are accountable for up to 40% of energy use in most countries (The World Business Council for Sustainable Development, 2007), out of which a large amount of energy is used for providing necessary indoor environmental circumstances inside the buildings for the occupants in terms of cooling and heating systems. This energy consumption can be reduced by employing passive and climate responsive design strategies to the buildings which require minimal energy for its working. Nevertheless, whichever design strategy is used on a building, its impact will only matter if the occupants of that space are comfortable in that environment.

Thermal comfort is defined as the condition of mind that expresses satisfaction with the thermal environment (ASHRAE, 2017). Traditional buildings that were constructed with vernacular principles are found to be more comfortable than contemporary buildings. (Dili , M.A, & T.Zacharia, 2010, p. 2147). There are not many studies on the thermal comfort of occupants in contemporary assembly buildings like churches as much as there are studies on regularly occupied buildings like offices and schools. This research is intended to study the thermal comfort of occupants of a recently constructed church at Kochi, Kerala. The church selected is a recently constructed naturally ventilated church which has a capacity of more than 1,000 people. The objectives of the research were to identify if there was occupant discomfort inside the church due to various environmental parameters and to discern the reasons for discomfort inside the church. The environmental factors are temperature, thermal radiation, humidity, and air speed and the personal factors are those of activity and clothing. (ASHRAE, 2017)

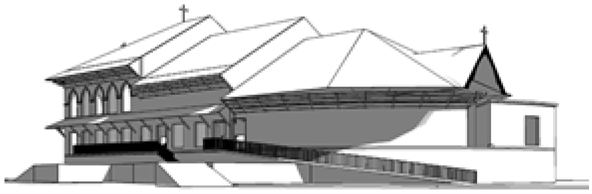

Figure 1: View of the church

Churchgoers who attend mass service tend to wear similar formal clothing and conduct similar activities. The estimated clothing insulation values of people vary between 0.36 and 0.54 clo (1 clo = 0.155 K•m2/W) and the metabolic rate is considered as 1.2 met (standing, relaxed) or 70 W/m2 (Karyono , Sri , & Sulistia, 2015, p. 928). As there is no change in activity or clothing, there will not be a significant change in the metabolic rates of each occupant. Hence, the personal factors affecting thermal comfort have not

Figure 2 Photographs of the church (Source: Author)

Figure 3 Neighbourhood context in a 100m radius from the church (Source: Google Map)

been considered as part of this research. Due to the short span of the research, field sampling was done for only a week in the critical month for monsoon (August 2019). The field data analysis is based on the current climatic factors and may not be applicable for values throughout the year.

The climate of Kochi is predominantly warm and humid. The temperature ranges from a minimum of 23°C in January to 33°C in May. The temperature ranges are similar in all the months. The diurnal temperature variation is not greater than 8°C in any month. Humidity levels greater than 60% are observed throughout the year. During the monsoon months of June, July, and August, the humidity levels increase up to 91%. The prevailing wind direction is from the North West and West. (India Meteorological Department, 2015, pp. 201-202). Figure 4 depicts the bioclimatic chart of Kochi (DeKay & Brown, 2001, p. 54). From the bioclimatic chart, it can be seen that none of the months fall in the comfort zone. Due to high humidity

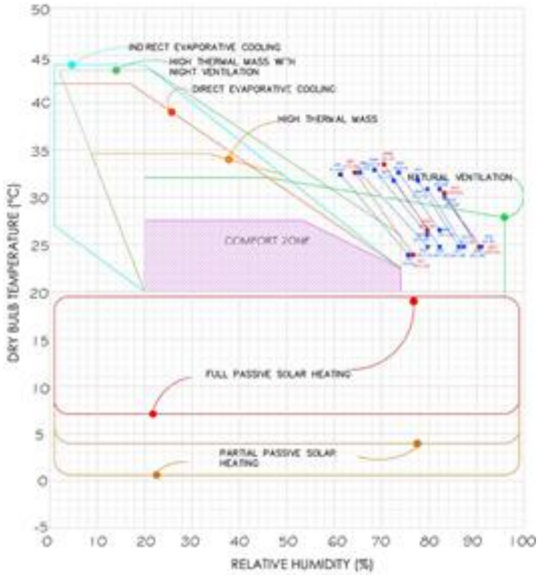

Figure 4 Bioclimatic chart of Kochi (Source: Author generated)

2. METHODOLOGY

Table 1: Research Methodology

OBJECTIVES	METHOD
To understand the critical months for the city concerning its temperature and humidity values and the wind speed.	Climate Study
To evaluate design strategies for a climate using bioclimatic chart of the city	Investigation of bioclimatic strategies
To quantitatively evaluate a representative month for further simulation (relative humidity, temperature, wind speed and wind direction)	In-situ measurement
To determine occupant comfort analysis (comfort parameters: thermal sensation, thermal preference, thermal comfort, thermal acceptability, air movement perception and air movement preference)	Occupant satisfaction surveys
To determine performance for whole year quantitative evaluation (solar shading analysis and wind flow analysis)	Building simulation tools

The research approach can be seen in Table 1. The level throughout the year, the only strategy that can bring comfort to people in the mornings are natural ventilation but for evening time, there is a need for artificial systems for ventilation.

Research focuses on the environmental parameters of thermal comfort as set by ASHRAE Standard.

There are two major methods for evaluating comfort in existing buildings - Occupant surveys and Environmental measurement. A long-term approach was followed for the occupant comfort analysis which was procured through occupant satisfaction surveys, whereas a short-term approach was followed for environmental measurements carried out by spot measurements during August. The part of the research which focuses on the whole year's quantitative evaluation is done through building simulation tools.

The field measurements were taken in the monsoon representative month of August 2019 for a period of 7 days. The parameters which were measured were: Ambient Temperature (°C), Relative Humidity (%), Wind Speed (m/s) and Wind Direction. A thermo-hygrometer and anemometer were used for the measurements. For the interior data for relative humidity and air temperature, the church was divided into a grid having 16 nodes as seen in figures 5 and 6, where humidity and air temperature were measured for 4 days at 3 representative times of the day- morning (8-10 am), noon (12-2 pm) and evening (4-6 pm). For exterior data, seven points were located along the site boundary as seen in Figure 7, to obtain exterior measurements of wind speed and direction for a day at 3-hour intervals in a day to find predominant wind direction on-site due to microclimatic conditions. For

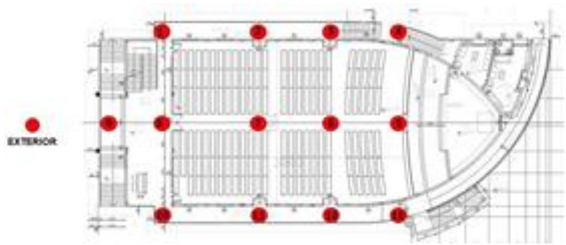

Figure 5 Measurement positions on the Ground floor

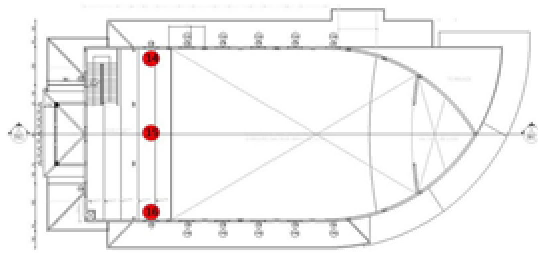

Figure 6 Measurement positions on the mezzanine floor

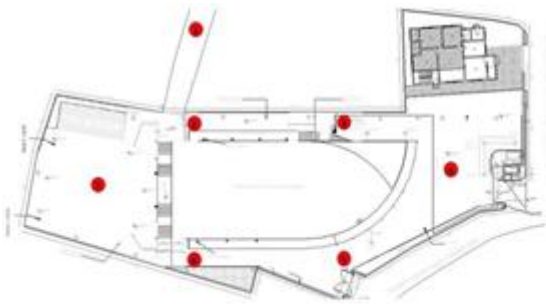

Figure 7 Measurement positions on the site

the interior data regarding wind speed and direction, the parameters were measured in the evening (4-6 pm) for 2 consecutive days at the selected points inside the church as seen in figures 5 and 6. It is to be noted that for taking the field readings, all the interior measurements were determined without any occupancy, at 1m level from the floor with all windows fully open during the time of measurements.

Occupant satisfaction surveys were administered to the occupants of the church via google forms. A total of 55 responses were obtained. The survey was intended for occupant satisfaction for the 3 main seasons of the city of Kochi – Summer, Monsoon, and Winter. The survey had close-ended and open- ended questions divided into three main sections: demographic data of respondents, all-year occupant perception and preference and occupant perception on reasons for discomfort (open-ended). The main intent of the survey was to understand occupant perception and preference of the various comfort parameters. This was analysed with respect to six parameters:

1. Thermal Sensation
2. Thermal Preference
3. Air Movement Perception
4. Air Movement Preference
5. Thermal comfort

6. Thermal acceptability

The solar shading analysis of the church was done for an entire year on Autodesk Ecotect Analysis 2010. This was done to understand if the openable windows at the accessible height on the North and South façade were receiving direct radiation, especially during the morning hours.

The air movement around the church was simulated using Autodesk Flow Design software. The airflow was simulated at 1m/s and the direction was taken from the South West as these were the predominant speed and wind direction obtained from the field measurements. The simulation was carried only for a representative day of the field measurement to check if the field readings and simulations for that day were correlating. The wind flow for analysis was taken at the 4m from the ground level, which is the height of the occupant seating inside the church.

3. DATA PRESENTATION AND ANALYSIS

The study consists of three major parts: occupant satisfaction surveys for understanding the subjective parameters, field measurements, and building simulation (shading and wind flow analysis) for understanding the objective parameters of thermal comfort.

3.1. Field Measurements

From the humidity measurements, as seen in Figures 8-10 which have the relative humidity readings on the Y axis and the measurement points on the X axis, it was observed that humidity inside the church was lesser than the IMD readings of the day. There were not any drastic changes in relative humidity at the different measurement points.

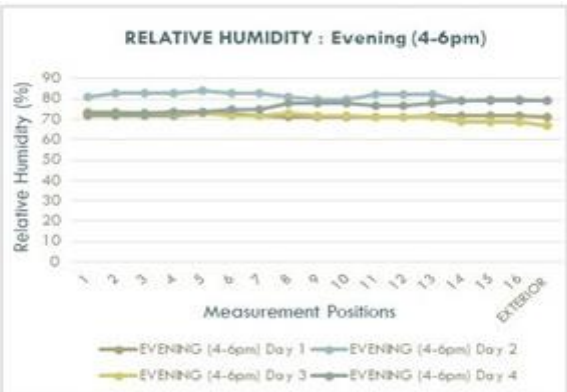

Figure 8 Relative Humidity measurements for the morning (Source: Author generated)

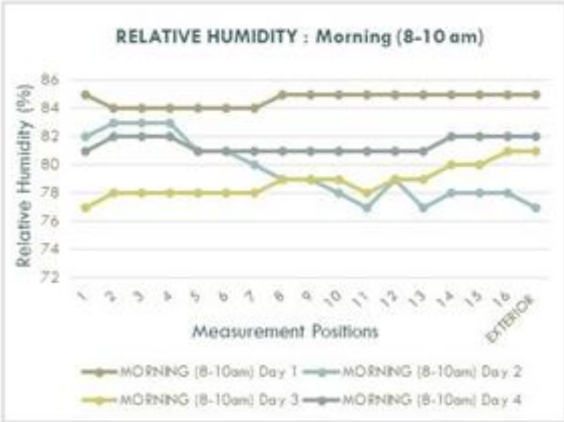

Figure 9 Relative Humidity measurements for the noon (Source: Author generated)

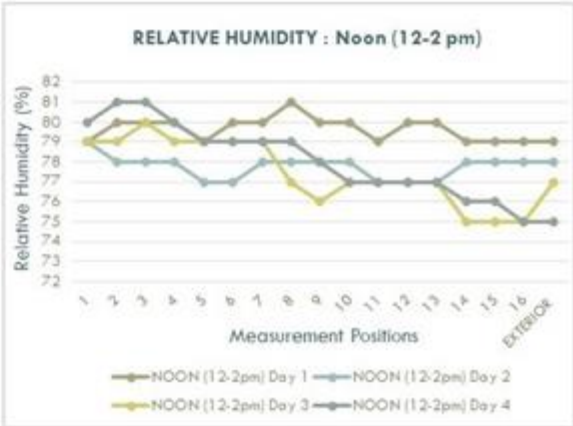

Figure 10 Relative Humidity measurements for the evening (Source: Author generated)

From the temperature measurements, as seen in Figures 11-13 which has temperature readings on Y axis, it was observed that temperatures at the mezzanine floor were higher than the ground floor.

From the exterior measurements at positions mentioned in Figure 7, for wind speed and direction as seen in Figures 14 and 15, it was observed that due to microclimatic conditions, the predominant wind

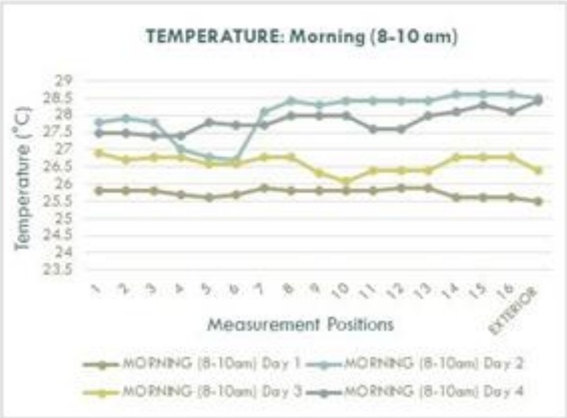

Figure 11 Temperature measurements for the morning (Source: Author generated)

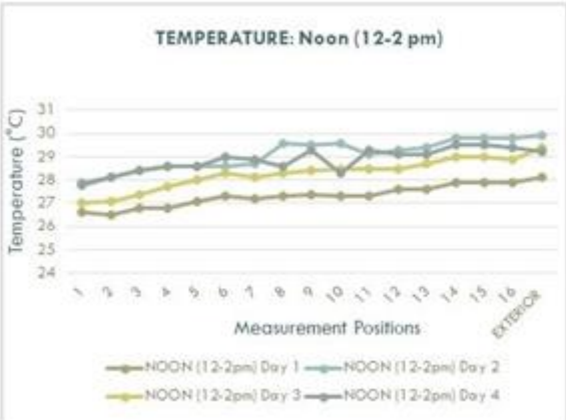

Figure 12 Temperature measurements for the noon (Source: Author generated)

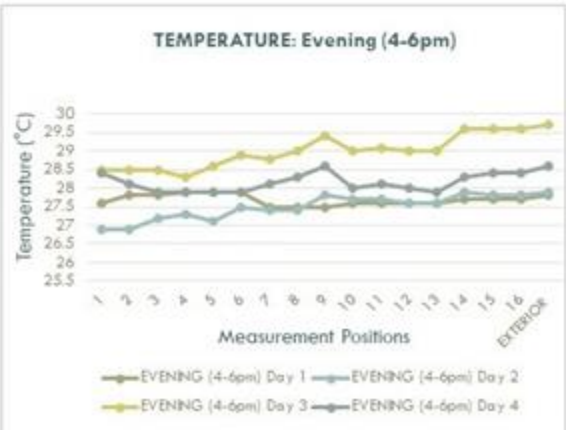

Figure 13 Temperature measurements for the evening (Source: Author generated)

direction was from South West and West (during the days of the study) and not from North West as per the IMD climate data.

From the interior measurements for wind speed and direction, as seen in Figures 16 and 17, it was observed that the air velocities near the windows of the church were maximum 0.4m/s and only up to 0.3m/s at the points inside the church without any

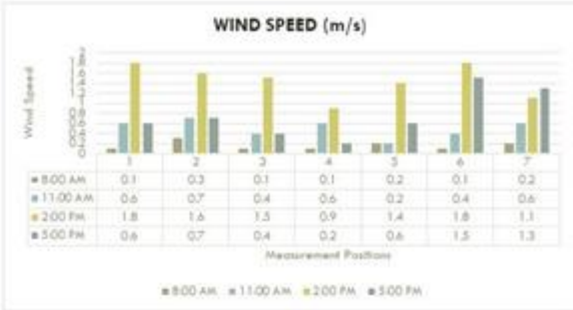

Figure 14 Graph depicting the wind speed on the various points outside the church for measurement timing at 3 hour intervals. (Source: Author generated)

WIND DIRECTION

POSITION	8:00 AM	11:00 AM	2:00 PM	5:00 PM	PREDOMINANT	
1	↗	→	↓	→	W	→
2	→	→	→	→	W	→
3	←	←	→	↓	E	←
4	↖	↑	↑	↑	S	↑
5	↖	↖	→	↑	SE	↖
6	↗	↑	→	↗	SW	↗
7	↗	↗	↘	→	SW	↗

Figure 15 Wind direction at the various points outside the church for measurement timing at 3 hour intervals. (Source: Author generated)

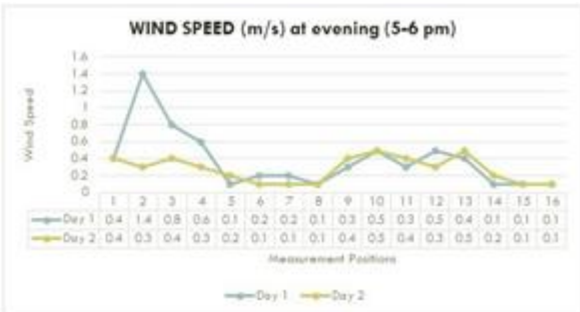

Figure 14 Graph depicting the wind speed on the various points outside the church for measurement timing at 3 hour intervals. (Source: Author generated)

Figure 14 Graph depicting the wind speed on the various points outside the church for measurement timing at 3 hour intervals. (Source: Author generated)

occupants. As per Beaufort scale wind speed of 1.6 - 3.3 m/s is required for wind to be felt on the face for comfort.

3.2. Occupant Satisfaction Survey

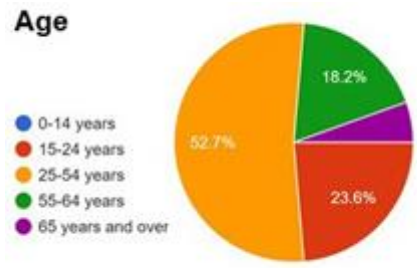

Figure 18 Chart showing the age group of the respondents (Source: Author generated)

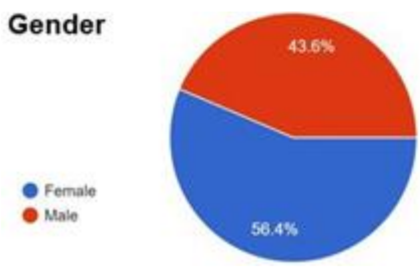

Figure 19 Chart showing the gender of the respondents (Source: Author generated)

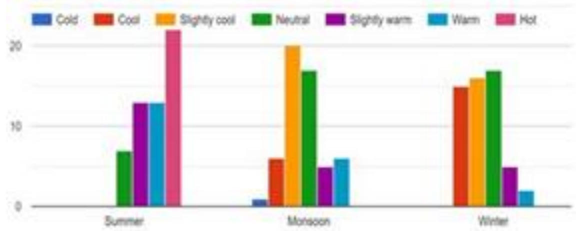

Figure 20 Thermal Sensation graph (Source: Author generated)

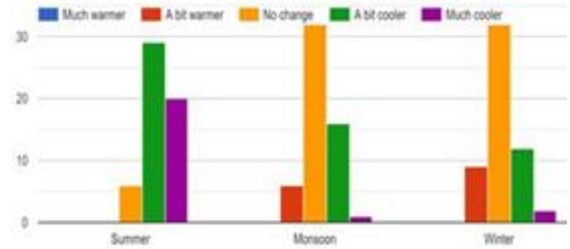

Figure 21 Thermal Preference graph (Source: Author generated)

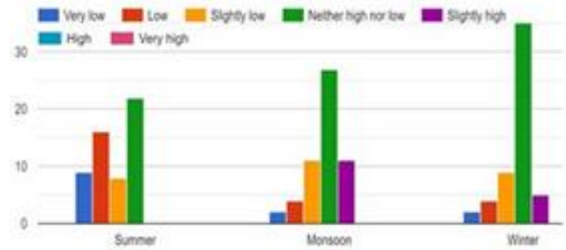

Figure 22 Air movement perception graph (Source: Author generated)

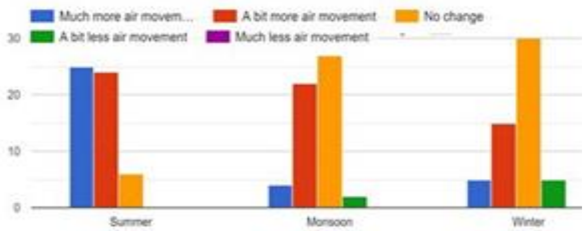

Figure 23 Air movement preference graph (Source: Author generated)

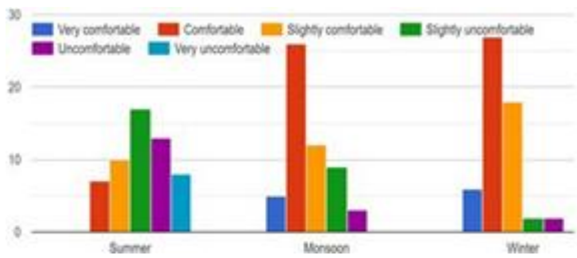

Figure 24 Thermal comfort graph (Source: Author generated)

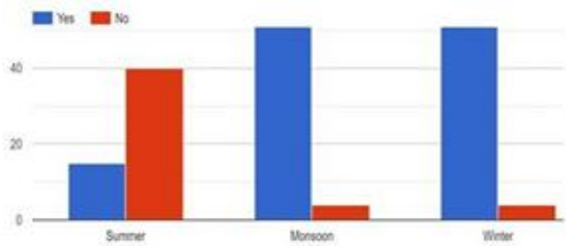

Figure 25 Thermal acceptability graph (Source: Author generated)

From the questionnaire survey, it was understood that the church is uncomfortable for a majority of the occupants only during the summer months and was relatively comfortable during monsoon and winter months.

The possible reasons for discomfort inside the church during summer as expressed by the respondents include: high outdoor temperatures, less air movement inside the church, insufficient or mispositioned fans, metal roof over the entire congregation space, dense neighbourhood blocking air movement and reducing wind speed, excessive sweating due to high temperatures added to the activity of when standing in a crowded space for more than 2 hours and closure of a jaali opening above the mezzanine floor due to addition of a false ceiling layer few years after construction. The possible reasons for discomfort inside the church during monsoon and winter as expressed by the respondents include in-sufficient air circulation inside the church, high humidity levels during monsoon and the noise of rain.

3.3. Shading Analysis

From the shading analysis, it was understood that the operable windows meant for ventilation were being shading during the daytime, throughout the year.

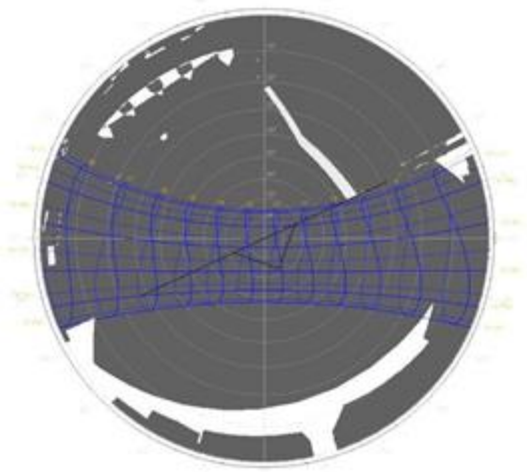

Figure 26 Stereographic diagram of solar shading of a window on South façade (Source: Author generated)

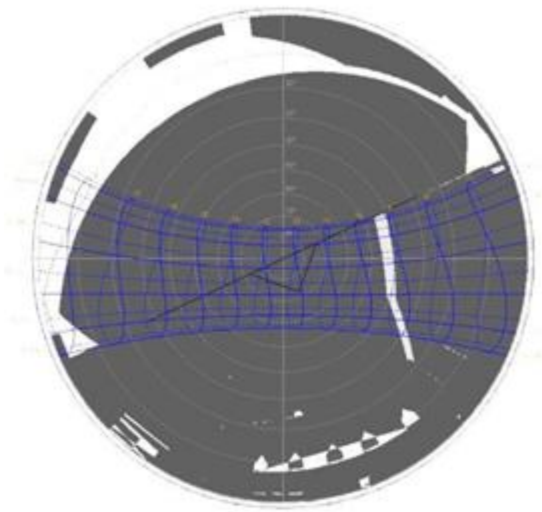

Figure 27 Stereographic diagram of solar shading of a window on North façade (Source: Author generated)

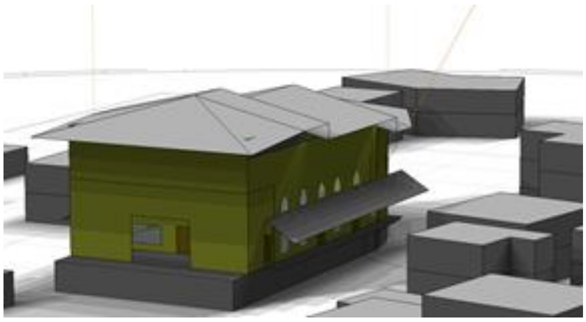

Figure 28 Shadow range on South Facade for April (Source: Author generated)

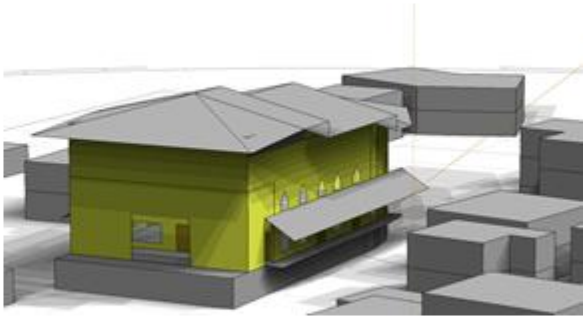

Figure 29 Shadow range on South Facade for December

(Source: Author generated)

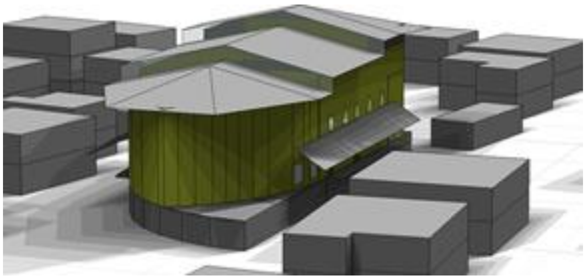

Figure 30 Shadow range on North Facade for April (Source: Author generated)

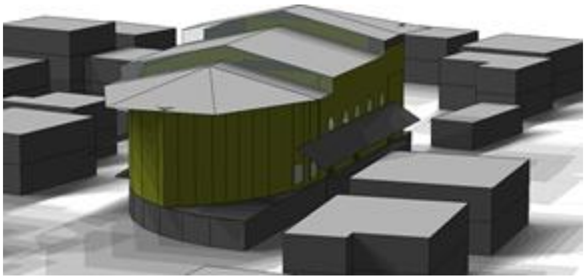

Figure 31 Shadow range on North Facade for December (Source: Author generated)

3.4 Wind Flow Analysis

Due to dense development, the velocity of wind on site is less than 1.2m/s. Due to the adjacent buildings, the orientation and shape of the church, the wind flow gets diverted from the West side. Hence, the amount of ventilation happening from the side facades is minimal. This analysis is thus correlating with the on-site measurements which showed that inside the church the wind speeds reduced to 0.1-0.3m/s.

4. INFERENCE

The research was carried out in many stages of primary study. From the climate study, it was found that July/August (monsoon) would be a critical month for discomfort due to high humidity levels. The bioclimatic chart of Kochi showed that none of the months falls into the comfort range. There is a need for ventilation strategies for enhancing comfort.

The field measurements of temperature and humidity showed that there is not much change in humidity readings at various points inside the church, whereas the temperatures on the mezzanine floor were considerably higher. The onsite predominant wind direction was found to be from South West and West (during the days of the study) and not from North West as per the IMD climate data. The wind speeds inside the church were found to be very low (up to 0.3 m/s) which is not sufficient for comfort conditions as per Beaufort scale.

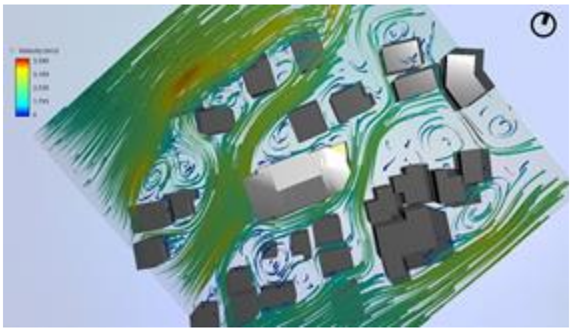

Figure 32 Wind flow analysis – Plan (Source: Author generated)

Figure 33 Wind flow analysis around the South façade (Source: Author generated)

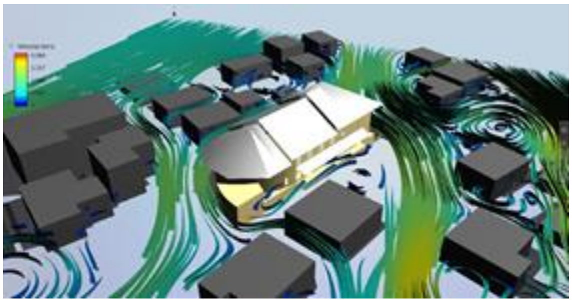

Figure 34 Wind flow analysis around the North façade (Source: Author generated)

The assumption that monsoon would be the season of highest discomfort was contradicted after the questionnaire survey when all the respondents felt that April/May (summer) months were more uncomfortable. This is because the people have adapted themselves to humidity where a slight increase in temperature is a cause of discomfort more than an increase in humidity levels.

The whole year solar shading was analysed for the façades of the church. It was observed that due to the shaded wide corridors on either side of the church, the windows at the ground floor were getting shaded throughout the year. Thus, radiative heat gain is not a factor that can be a cause of discomfort. The wind flow analysis done for a day considering the wind speed and direction obtained from the field measurements, further validated the on-site readings. The simulation showed that due to adjacent buildings and the orientation of the church, the wind flow was diverted from the rear side. Thus, significantly reduced the air movement inside the church which is a major parameter of the thermal comfort of occupants.

5. CONCLUSIONS

A subjective factor like thermal comfort required different methods for analysing it. The research comprised of field measurements, questionnaire surveys, and simulations for analysing the thermal comfort conditions of occupants in a church. From all the methods it could be understood that the occupants were comfortable with the existing conditions in all seasons other than summers due to adaptive comfort. Thus, there is a need for enhancing the comfort of occupants during the summer season.

For a city like Kochi, enhancing the ventilation strategies inside a building is thus one of the most efficient measures to improve comfort. Thus, further studies could be done to validate passive strategies that could help in strengthening the comfort of occupants in summer.

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