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Thermal comfort in healthcare waste management buildings: insights from Seti Hospital, Dhangadhi, Nepal

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Abstract

Thermal comfort in waste management studies is emerging as a growing concern, particularly in ensuring sustainable goals align with the well-being of workers. Under the scorching summer temperatures of up to 42.2°C, waste management workers at Seti Provincial Hospital, Dhangadhi, Nepal, experience significant thermal discomfort while handling infectious waste. Recognizing this challenge, this study investigates the thermal comfort of waste management workers at Seti Provincial Hospital, Dhangadhi, Nepal, and the impact of an internally heat-generating autoclave machine on the building's material and thermal performance. Despite extensive literature on waste management principles and the functional design of healthcare waste management blocks, there is a noticeable gap regarding thermal comfort in such facilities. This research aims to fill that gap by focusing on healthcare waste management buildings in subtropical climatic conditions in Nepal. The research uses both quantitative and qualitative methods. Indoor temperatures in the treatment zone and office space were measured and compared with outdoor temperatures over a seven-day period. Moreover, a twice-daily questionnaire survey over a week assessed workers' thermal sensations and preferences. Surface temperatures inside and outside the treatment zone were recorded to analyze the building envelope's response to the autoclave's heat generation. Findings indicate that workers experience extreme thermal discomfort during summer, highlighting the necessity for strategic autoclave placement to optimize thermal comfort and the adoption of passive design strategies during the design phase.

Keywords: *Thermal comfort, waste management, healthcare facilities, autoclave machine, subtropical climate, passive design strategy*

1 Introduction

Healthcare Waste Management (HCWM) involves the systematic handling of waste materials generated from healthcare activities, research related to health, and laboratories associated with health. In Nepal, a developing country experiencing rapid waste generation and inadequate infrastructure, HCWM presents a significant challenge. This is particularly pronounced in the Terai region, where most hospitals are situated and face difficult working conditions due to high temperatures. Poor HCWM practices not only pose risk to public health and environmental pollution but also impact resource depletion. Efforts to improve HCWM infrastructure have increased recently; however, there remains a critical need to prioritize thermal comfort for waste workers and adopt energy-efficient technologies and practices to protect public health, mitigate environmental impact, and promote sustainable development. Workers in these facilities, including waste handlers and autoclave operators, operate in high-temperature environments with intense metabolic activity (GON, 2020).

Internationally, research in this field has focused on themes such as waste minimization, sustainable management, policy-making; incineration and its environmental impacts, hazardous waste management practices; and occupational safety and training (Ranjbari & Esfandabadi, 2022). Energy optimization strategies, including integrated façade systems that optimize window-to-wall ratio, day-lighting, and minimizing energy consumptions for heating, cooling, artificial lighting and peak electricity, offer substantial energy savings (International Energy Agency, 2013). Building materials with lower U-value perform better in sub-tropical climates but the strategic combination of thermal mass and insulation is crucial, especially in areas impacted by heat generating equipment like autoclaves. Proper ventilation is also essential to manage odors produced during treatment process. Studies drawing from the works of Florence Nightingale underscore the significant impact of environmental factors on health outcomes, linking improved environmental conditions to reduced mortality rates (Emmanuel, 2020). Design elements that enhance natural ventilation, sunlight exposure, and incorporate sustainable features play a significant role in infection prevention and control. Innovative solutions such as heat insulating paints have shown potential to reduce cooling loads and indoor temperatures significantly (MIRACOOL, 2022).

In this context, despite increasing attention to waste management, there remains a notable gap in literature concerning the design facilities that prioritize thermal comfort, particularly in sub-tropical climates where many healthcare facilities are located. This study addresses this gap by focusing on the HCWM block at Seti Provincial Hospital, Dhangadhi, aiming to identify optimal envelope designs that enhance indoor thermal comfort. Special emphasis is placed on the treatment room and strategic placement of autoclave machines The study's specific objectives are i) to asses thermal comfort in the selected case block, ii) to analyze the impacts of autoclave-generated heat on the building envelope and occupants, and iii) to provide general design strategies for efficient HCWM blocks using Mahoney's table and Bioclimatic analysis. Implementing these strategies will improve thermal comfort in working environment for operators and waste workers, contributing to energy efficiency and sustainability goals.

2 Materials and Methods

This research employed both quantitative and qualitative methods to study the thermal comfort of waste management workers and the impact of an autoclave machine on building's thermal performance in order to recommend general design strategies for improving thermal comfort by highlighting the significance of local climate at Seti Provincial Hospital, Dhangadhi, Nepal.

2.1 Assessing thermal comfort

Nicol's graph is used to determine thermal comfort range of Dhangadhi which aids in making informed decisions about thermal comfort, ensuring that occupants experience pleasant conditions while minimizing energy consumption. A perception survey collected demographic information and assessed thermal sensations and preferences using a 7-point scale. Fifteen staff members, including the autoclave operator and waste management supervisor, participated. Questionnaire survey was carried out twice a day for a week during peak activity hour that included information of gender, age, income and literacy. In addition to this, the survey covered building satisfaction regarding thermal comfort, indoor air quality, relative humidity, and clothing.

2.2 Impact assessment of autoclave-generated heat

Field measurements were integral to data collection. It included air temperature data, recorded both indoors and outdoors, to understand changes over time during working hours and passive cooling at night. Temperature loggers were used to measure air temperatures over seven days (August 03, 2023 - August 09, 2023) at 10-minute intervals. Sensors were placed at a height of 7 feet indoors and 3 feet near the autoclave machine in the treatment room with outdoor sensors carefully positioned to avoid direct sunlight and rainfall. A TR-76Ui recorder measured CO_2 levels, relative humidity, and indoor air temperature in the treatment room over seven days. This data helped analyze variations with the autoclave machine running during working hours and off at night. Surface temperatures were measured using a remote sensing thermometer in all directions of the treatment zone to assess the effects of the autoclave machine on different building materials. Temperature logger sensors were placed outside and inside the office, as shown in the Figure 1, with CO_2 recorder in treatment room.

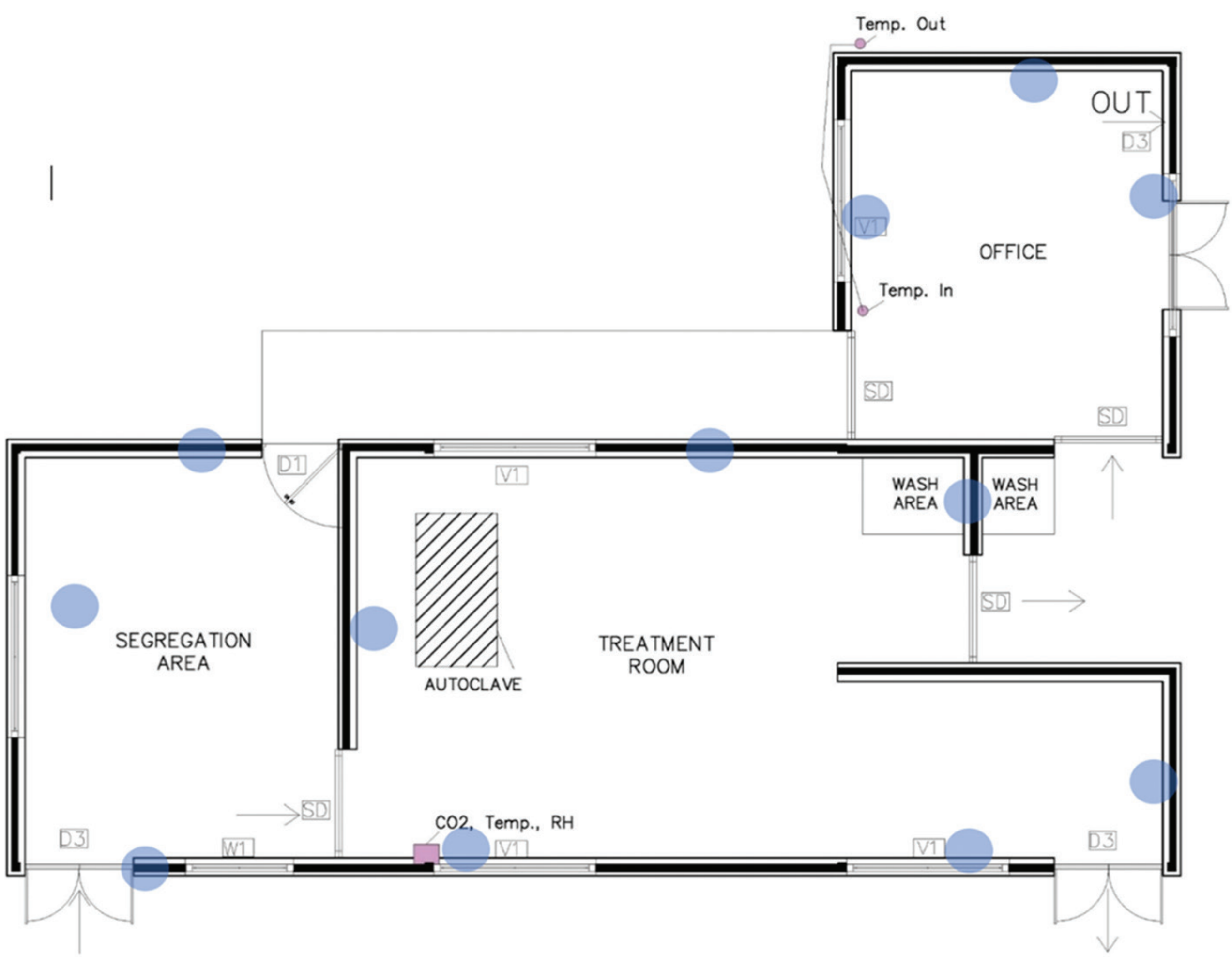

Figure 1: Placement of measurement devices

Figure 2 depicts surface temperatures in all directions within the treatment room, including floor and ceiling temperatures.

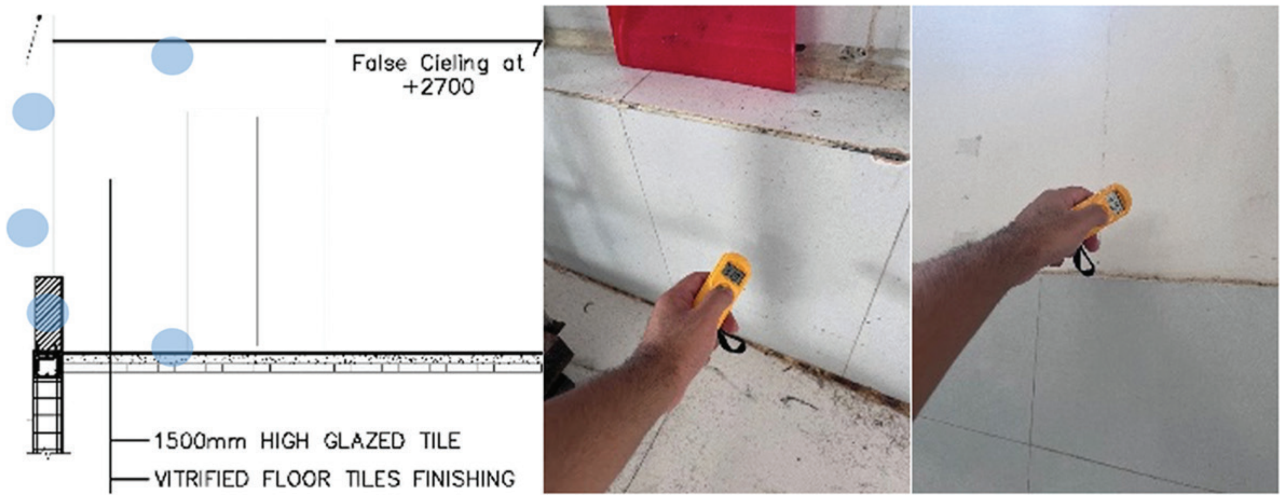

Figure 2: Surface temperature measurement

2.3 Climate analysis for design strategies

Multiple data sources and analytical methods were used to develop integrated design strategies specific to HCWM blocks based on climatic study. The study utilized Climate Consultant 6.0 for bioclimatic analysis, considering factors like solar radiation, temperature variations, wind patterns, and humidity to optimize natural resources, enhance thermal comfort, and minimize energy consumption. Moreover, the Mahoney Table analysis was performed to assess the application of climate-appropriate design, analyzing monthly climatic data (temperature, humidity, rainfall) to provide recommendations for climate-responsive and sustainable architecture. Climatic data including monthly average temperature, relative humidity, and precipitation for the past 10 years (2012-2022) were collected from Department of Hydrology and Meteorology for this purpose (Table 1).

Table 1: Weather station details

Station index	Name	District	Latitude	Longitude	Elevation
0209	Dhangadhi	Kailali	28.81273	80.55995	184

2.4 Site details, infrastructure and case study building

In recent years, various development organizations have supported multiple provincial and district-level government hospitals across Nepal, many of which are located in the Terai region. The types of infrastructure support in HCWM observed include new blocks, functionally retrofitted block (renovation of existing structures) and mixed block (additional block component to existing infrastructure). Most newly constructed blocks have incorporated sandwich panels as façade material for insulation, CGI roofing sheets, aluminum openings and steel framed structure. Space planning typically revolves around available resources and budget constraints, often prioritizing the utilization of existing infrastructure. Field observations, particularly in areas like the treatment room housing autoclave machine, focused on building materials. Detailed building typology and location plans were collected to assess the significance of surrounding blocks during data analysis, as illustrated in Figure 3.

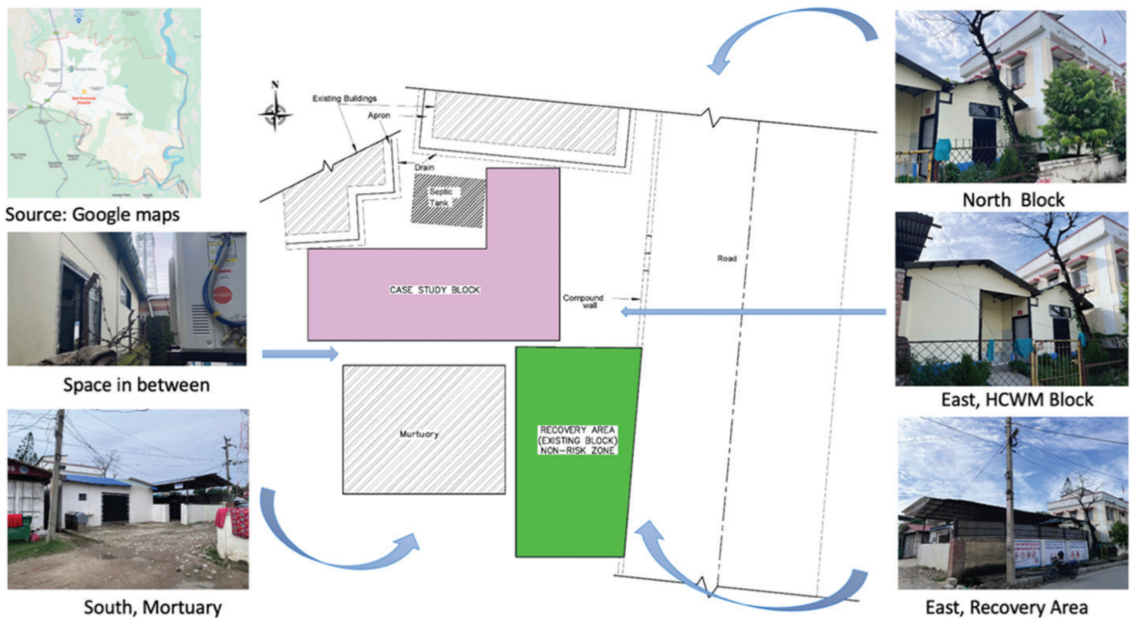

Figure 3: Location plan of Case study block

A newly constructed HCWM block at Seti Provincial Hospital in Dhangadhi (coordinates: 28.7044026 N, 80.5884479 E.) was selected as a case study (Figure 4). The floor plan in Figure 5 illustrates the three main spaces in the selected waste block; segregation space, treatment space, and office space. The autoclave machine is placed on the northwest corner of the treatment room, 2' offset from the segregation room, which is partitioned in between. Moreover, there is also a steam outlet located on the eastward elevation near office door. The block has an open space to the east due to set back from the road and the northwest area avoids the underground septic tank.

Figure 4: Selected HCWM block

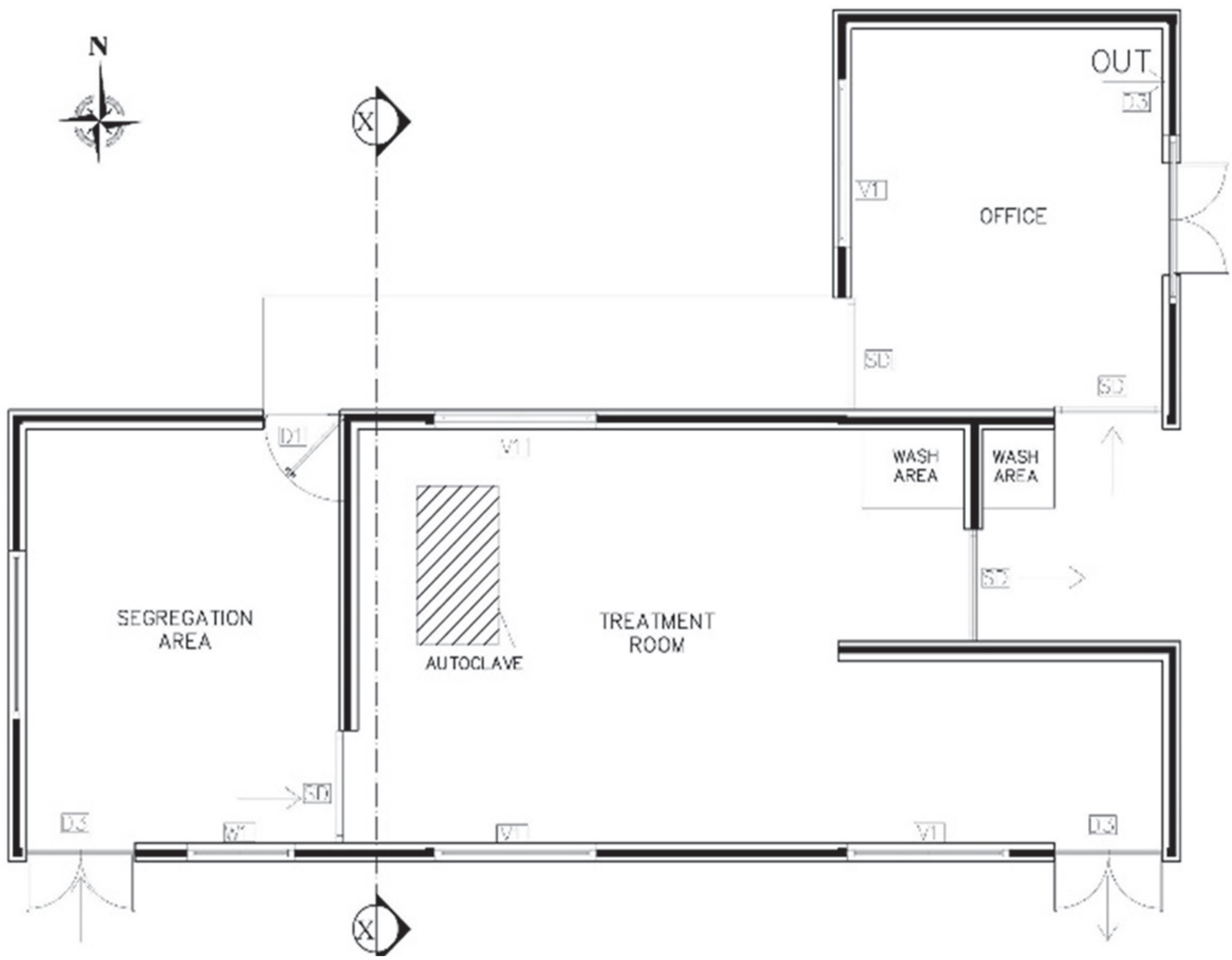

Figure 5: Floor plan of selected HCWM block

As shown in Figures 6, the envelope of the HCWM block comprises of three different sections of the building material. The lower section up to 1'6" height is a 9" brick wall, which is tiled on the inner side up to 5'. The rest of the superstructure erected with a 4" concrete sandwich panel board. The roofing material is CGI of 0.41 mm thickness, with a false ceiling later added due to extreme temperatures within the block during peak summer. The openings for ventilation is aluminum with outer metal framed doors.

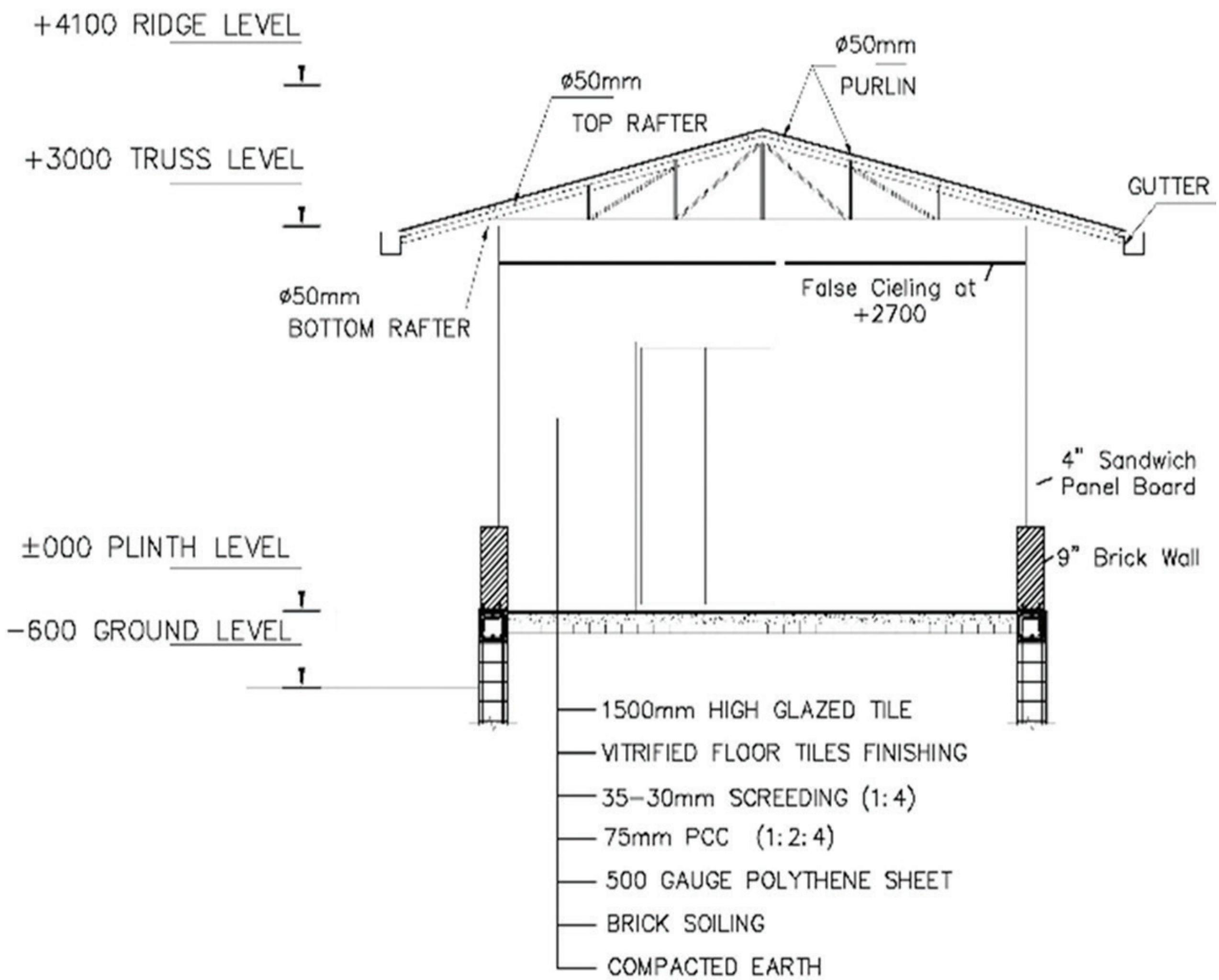

Figure 6: Section at X-X (envelope material composition)

2.4.1 Autoclave operation

The sterilization cycle is performed 3-4 times daily, depending on the amount of waste generated. The process begins with a pre-heat stage lasting 45 minutes to 1 hour, followed by an initial treatment phase that takes about 1 hour 30 minutes to complete. Subsequent cycles throughout the day are slightly shorter, taking 10 to 15 minutes less than the initial cycle as the autoclave machine reaches operating temperature. Sterilization occurs at 121°c. During the process, a foul odor is emitted through the steam outlet as can be referred from Figure 7.

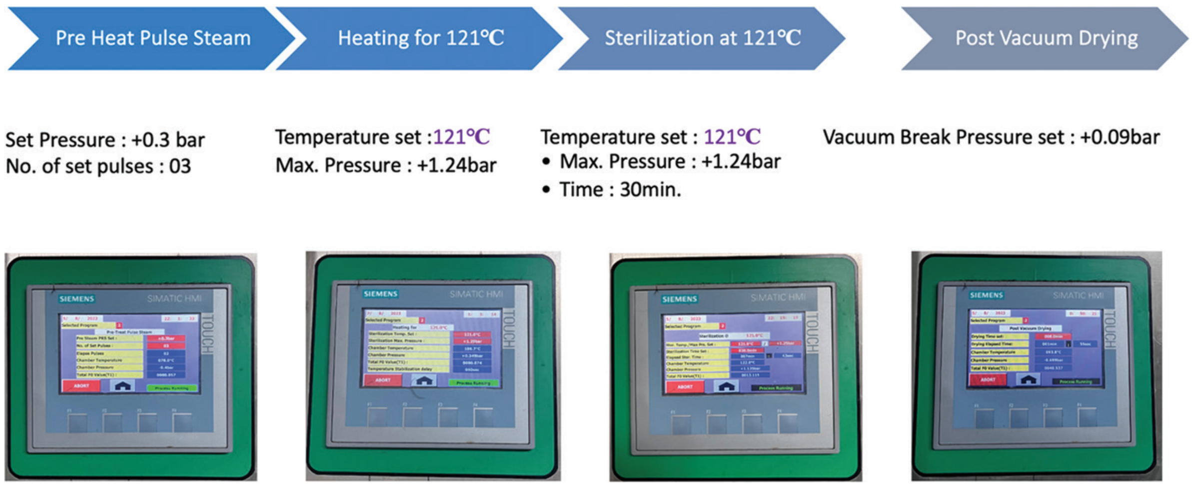

Figure 7: Sterilization stages (Autoclave display settings)

3 Results and Discussion

3.1 Thermal comfort analysis

Nicol's comfort temperature intersects with average mean temperature only during April and mid-September. Throughout the rest of the year, temperatures are mostly hotter and significantly colder during winter compared to the comfort temperature. According to Nicol's graph in Figure 8, the comfort temperature of Dhangadhi ranges from a lower 20.3°C to a maximum of 29.3°C. This indicates that for much of the year, the thermal environment is outside the comfort range, necessitating intervention for improved thermal conditions.

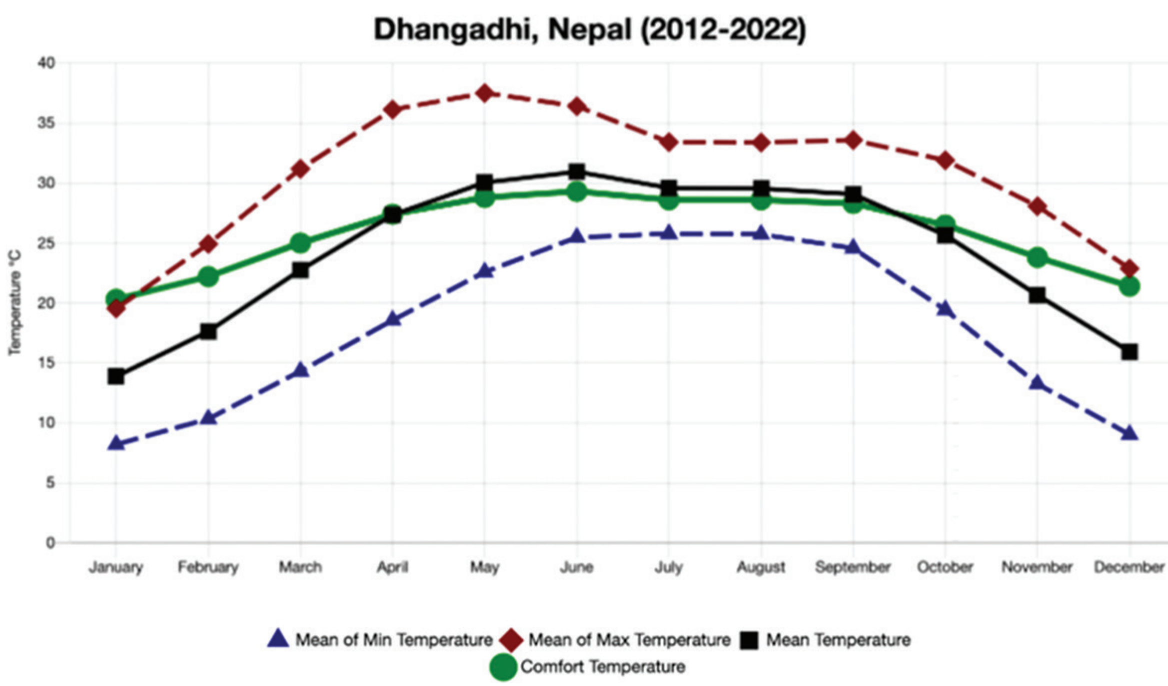

Figure 8: Nicol's graph plotted with DHM data

The thermal comfort sensation and preference were assessed through participation of fifteen occupants. Table 2 indicates that the majority of surveyed waste workers felt extremely hot and prefer a cooler thermal space. The thermal comfort survey showed extreme dissatisfaction, with 77% of workers reporting a sensation of heat and 95% preferring a cooler environment. This highlights the need for immediate interventions to improve thermal comfort, such as enhanced ventilation, shading, and potentially relocating the autoclave machine to minimize its impact on adjacent spaces. The results reveal significant thermal discomfort for waste management workers at Seti Provincial Hospital due to high indoor temperatures, especially in the treatment room with the autoclave machine.

Table 2: Percentage of thermal sensation and preference

Scale	Thermal Sensation		Thermal Preference	
	Number of vote	**Percentage (%)**	**Number of vote**	**Percentage (%)**
1	77	92	-	-
2	7	8	-	-
3	-	-	-	-
4	-	-	4	5
5	-	-	80	95
6	-	-	-	-
7	-	-	-	-
Total	84	100	84	100

3.2 Impact analysis of autoclave-generated heat

3.2.1 Air temperature

As shown in Figure 9, over the seven-day survey period, outdoor temperatures were consistently lower than indoor temperatures. The temperature in the office room spiked around 16:30 PM due to direct exposure to the west during sunset, with no shading. The temperature gradually cooled down during the night, while the temperature in the treatment room slowly rose from 9:00 AM as the autoclave was used during the day. The office room did not appear to be affected by the heat generated by the autoclave in the treatment room. The indoor and outdoor air temperature in the office showed a similar pattern, maintaining an average temperature difference of about 1.5 degree Celsius, as shown in Figure 12. It is also noted that the temperature in the treatment room remained consistently higher than in other spaces, including outdoors, throughout the study period. The temperature gradually increased with the pre-heating process of autoclave machine and steadily declined after turning off the machine, making this a major factor for contributing to the indoor temperature increase.

A significant finding is the importance of the autoclave machine's placement in designing the layout complimenting functional waste management practices as the heat generated by autoclave affects adjacent spaces and airflow through these spaces can impact thermal comfort as well. The consistent higher temperatures in the treatment room highlight the need for better thermal management and strategic placement of heat-generating equipment. The data also reveal the impact of external factors, such as solar gain in the office room during sunset, underscoring the importance of shading and other passive cooling strategies.

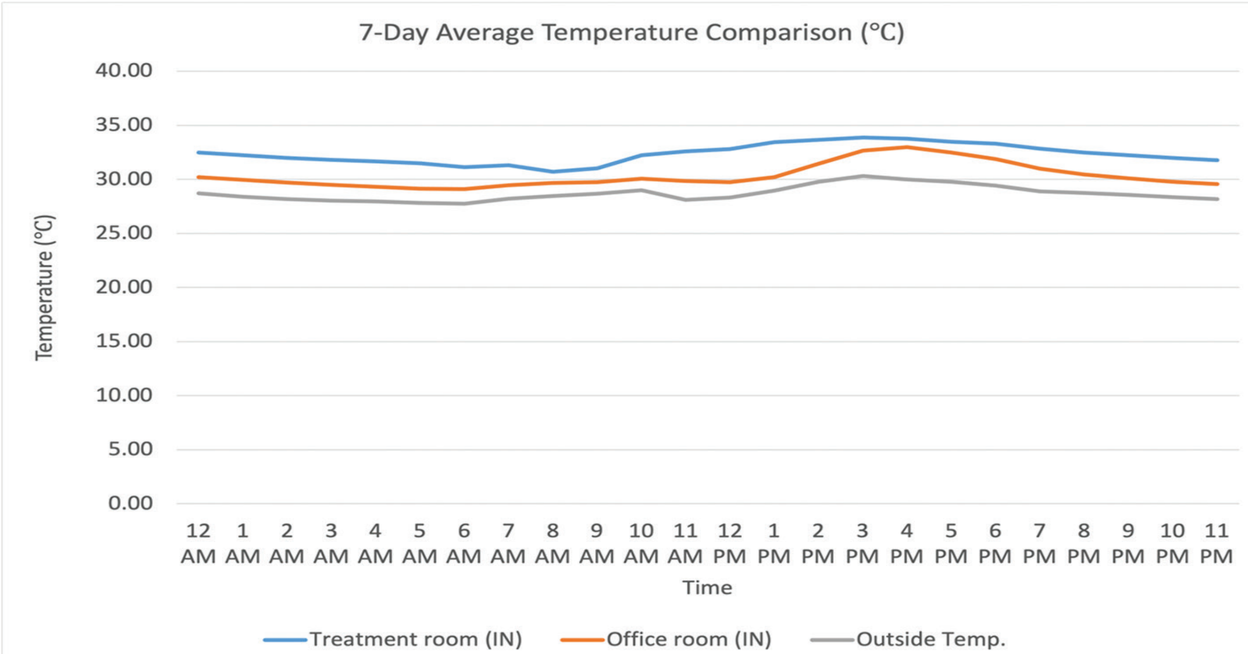

Figure 9: Air temperature comparison (observed data)

3.2.2 Surface temperature of superstructure

As shown in Figure 10, the surface temperature measured over seven consecutive days indicated that the highest temperature was on the vertical wall surface adjacent to the autoclave machine (west wall). The brick wall with tiling had the lowest minimum temperature, maintaining an average difference of 2℃ compared to the sandwich panel. The sandwich panel with tile cladding maintained an average of about 1℃ lower surface temperature than that without tile cladding. This data suggests that material choice and cladding significantly affect the surface temperature, highlighting the importance of selecting appropriate materials for thermal management.

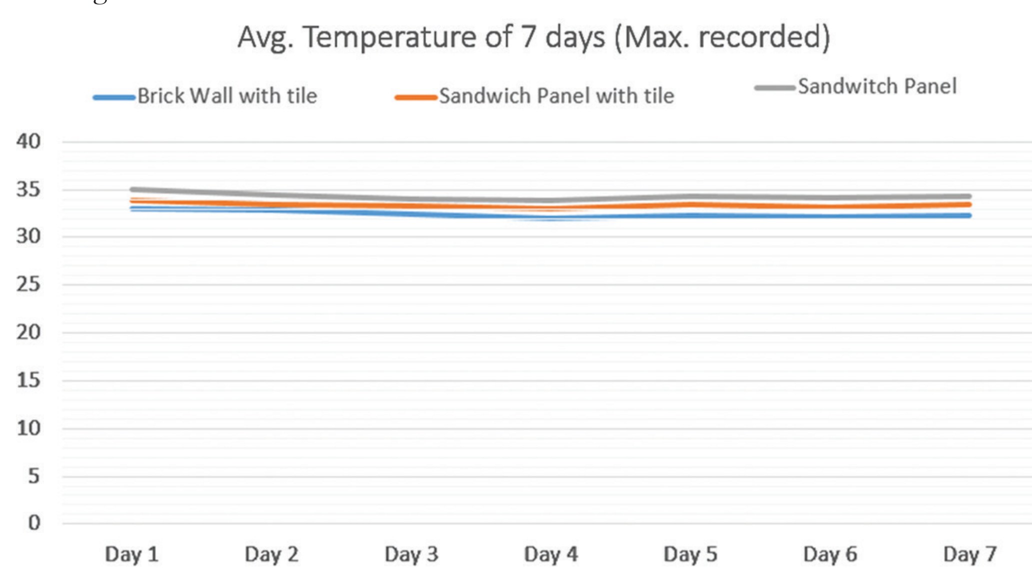

Figure 10: Surface temperature comparison (observed data)

3.2.3 CO_2 and relative humidity (treatment room)

As shown in Figure 11, the average CO_2 readings peaked at 519.88 ppm at 7:00 AM before the opening of doors and declined throughout the day, staying within the safe limits of 400 – 700 ppm during the study period. However, relative humidity (RH) levels spiked during the preheating process of the autoclave machine and remained above comfortable levels throughout the study period. This indicates that while CO2 levels were managed effectively, the RH levels require better control, possibly through improved ventilation or dehumidification strategies.

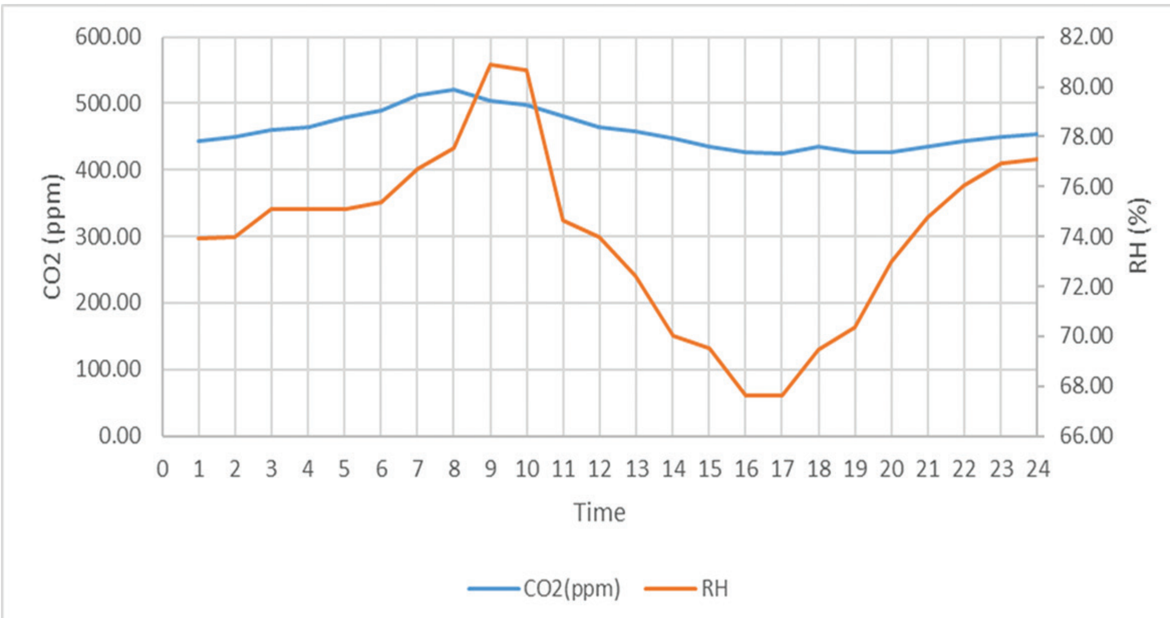

Figure 11: CO2 readings and RH in treatment room (observed data)

3.3 Integrated design strategies

Climate responsive design strategies suggested by Mahoney's table (Table 3) and bioclimatic analysis (Table 4) specifically for the HCWM block include North-South orientation, single banked room space for consistent air movement, medium opening (20-40%), heavy thermal mass for the superstructure, light insulated roofs, and shading provisions for sunlight and rain.

Table 3: Mahoney table results

Design component	Design strategies as per indicator
Layout	Orientation north and south (long axis east–west)
Spacing	Open spacing for breeze penetration, but protection from hot and cold wind
Air movement	Rooms single banked, permanent provision for air movement
Openings	Medium openings, 20–40%
Walls	Heavy external and internal walls
Roofs	Light insulated roofs
Rain protection	Protection from heavy rain as necessary
Position of openings	In north and south walls at body height on windward side
Protection of openings	Exclude direct sunlight, provide protection from rain
Walls and floors	Heavy, over 8h time-lag
External features	Space for outdoor sleeping, adequate rainwater drainage

Table 4: Bioclimatic analysis for indoor comfort

Thermal Comfort %	Hrs.	Design Strategies
15.9	1395	Natural Comfort
23.2	2031	Sun shading of windows
6.6	582	High Thermal mass
9.2	809	High thermal mass night flushed
4.1	358	Natural ventilation cooling
11.2	979	Fan-forced ventilation
17.2	1509	Internal heat gain
5.8	511	Passive solar direct gain high mass

The design strategies based on the bioclimatic analysis exhibited that indoor comfort hours can be increased from 16% ((Figure 12) to 50% (Figures 13) by adopting strategies such as sun shading of windows, high thermal mass, natural ventilation, and passive solar direct gain high mass. This substantial increase in comfort underscores the effectiveness of climate-responsive design strategies (Table 4).

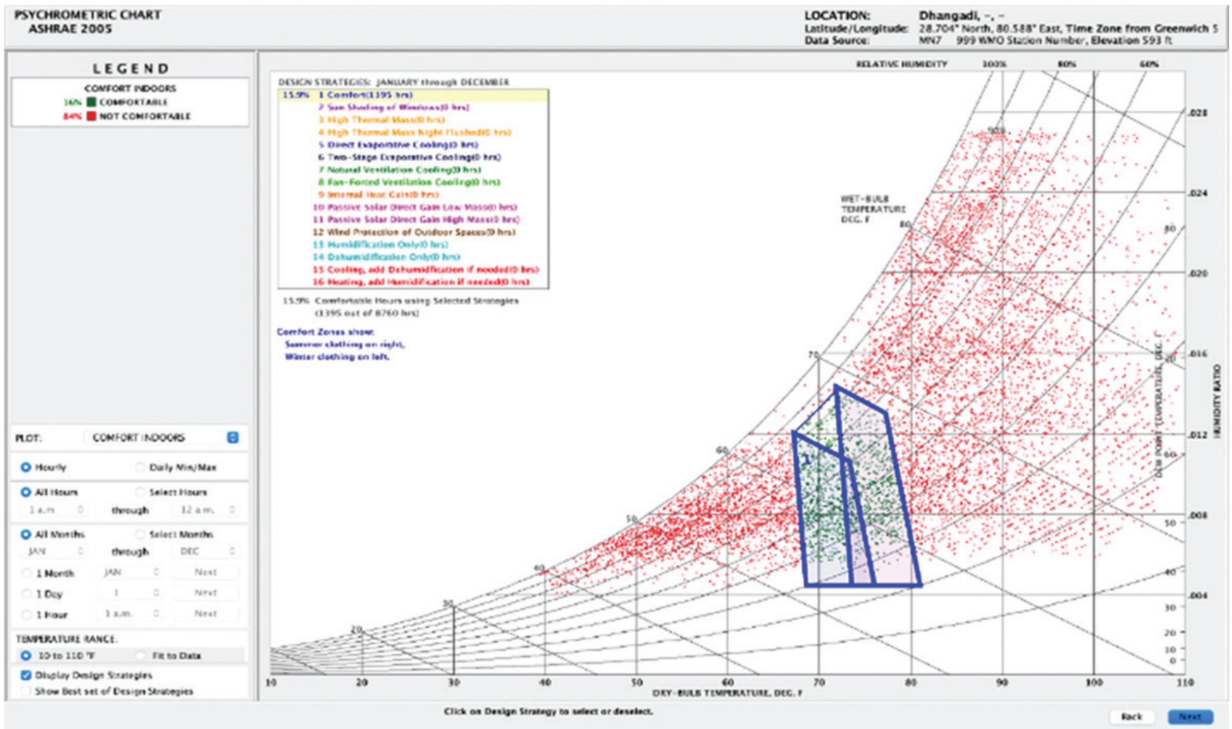

Figure 12: Thermal comfort (16%) without considering passive design strategies
(Source: Climate consultant 6.0)

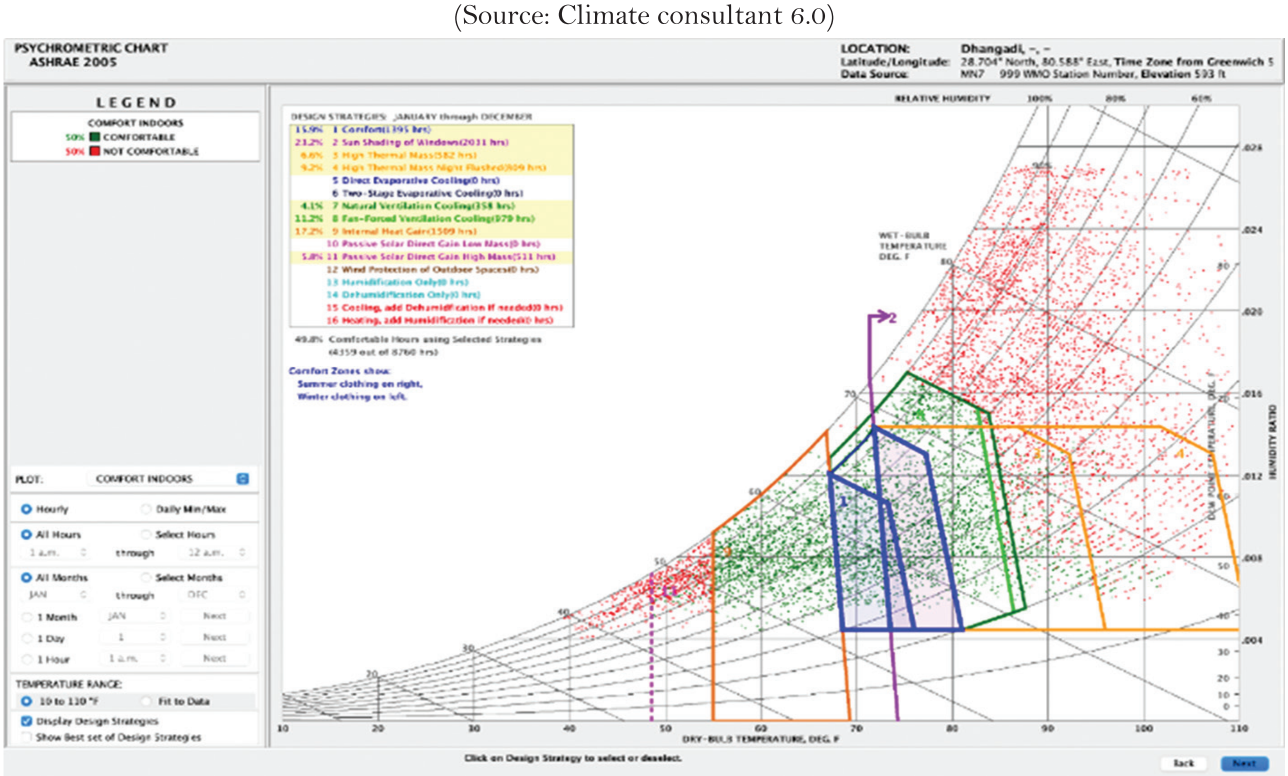

Figure 13: Thermal comfort (50%) adapting passive design strategies
(Source: Climate consultant 6.0)

This demonstrates the potential for significant improvements in thermal comfort contributing to energy efficiency through thoughtful design. The findings support the necessity of integrating these strategies into the design and layout of healthcare waste management facilities to improve working conditions and overall efficiency.

Further, simulations and detailed analysis of heat transmission through building materials will be crucial in optimizing the design and ensuring a comfortable environment for the workers. The correlation between surface temperature data and material choices emphasizes the importance of selecting appropriate building materials and cladding to mitigate heat buildup. Addressing the RH levels and worker thermal preferences through targeted design improvements can lead to a more comfortable and efficient working environment.

4 Conclusions

This study aimed to address three key objectives; studying thermal comfort, investigating the effects of the autoclave machine on the building envelope and occupants, and proposing general design strategies for HCWM block. The findings indicate that occupants experience significant discomfort during summer, with the placement of the autoclave machine in the treatment zone contributing to an internal temperature that is, on average, 2℃ higher than the office area. The selected envelope material increased this discomfort, recording temperatures higher than the outdoor temperature over a 7-day period. In contrast, a composite material with a higher thermal mass, combined with insulation, could potentially improve comfort in the treatment room. On-site measurements revealed that a brick wall with tiling had the lowest surface temperature, with an average difference of 2℃ compared to a sandwich panel. Furthermore, a sandwich panel with tile cladding had an average surface temperature 1℃ lower than one without tile cladding, indicating a better response to the heat source within the block. The study also found that the adoption of passive design strategies could increase thermal comfort by 34%.

The practical significance of these findings lies in their immediate applicability to improve working conditions for waste management workers in healthcare facilities by using materials with higher thermal mass and insulation and optimizing the placement of heat-generating equipment, significantly enhancing thermal comfort. These insights can be generalized to similar healthcare waste management facilities in subtropical climates, providing a blueprint for designing more comfortable and efficient HCWM blocks. Moreover, the broader implications extend to sustainable building design for energy efficiency in healthcare settings, highlighting the importance of considering thermal comfort in the design phase.

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