Evaluating the Feasibility of Reducing Cooling Loads of Tropical Building Using Phase Change Material-Based Curtain

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I. INTRODUCTION

Buildings in tropical climates have significant cooling demand due to high ambient temperatures and intense solar radiation, resulting in reliance on air conditioning and high electricity consumption, especially during peak daytime hours. This study explores the feasibility of reducing cooling loads in tropical buildings through the integration of phase change material (PCM)-incorporated screens. PCMs are capable of storing and releasing thermal energy during phase transitions, making them suitable for indoor temperature regulation. By integrating PCM into curtain systems, the material can reduce indoor heat, especially during peak hours (1100 hours to 1500 hours), when cooling demand is highest. This paper evaluates the effectiveness of this approach and investigates key factors such as PCM selection, climatic conditions and building system compatibility. The study aims to demonstrate how PCM-incorporated curtains can contribute to increasing the energy efficiency of tropical buildings.

II. EXPERIMENTAL STUDY

A. Literature review

According to [1], 32% of the worldwide energy consumption is expended towards fulfilling the energy requirements of the building sector. Out of which more than 50% is used for air conditioning (AC) systems mainly for space cooling in tropical buildings. Air conditioning is a process of conditioning air quality to a specific temperature and humidity to provide thermal comfort for occupants. During 1100HRS – 1300HRS on a typical day in tropical countries like Sri Lanka, the maximum temperature occurs outside a building [2], [3]. Due to solar heat gain through windows, walls and air leakages from doors/windows of a building, indoor temperature also goes higher. It is defined as the external heat gain. Internal heat gain occurs mainly due to humans, machines and equipment inside the building. Therefore, within those periods of cooling load/conditioned load: *the rate of energy removal required to maintain an indoor environment at a desired temperature and humidity condition* [4] goes higher. A curtain made with these PCMs will be a good option to reduce solar heat gain that comes through windows.

The main contribution of building energy consumption attributes is heating, ventilation, and air conditioning (HVAC). The cooling load is one of the critical factors in designing /sizing an air conditioning system for a given building zone. Cooling load reduction is one of the main solutions to reduce energy consumption in the building sector. Solar heat directly affects the temperature rise of the building. If the solar heat gain to the building is reduced, it reduces the required cooling load.

Transmission heat gain through the glass

$$Q = U.A.CLTD ----------------1$$

U = Overall heat transfer coefficient (W/m^2 °C)

A = Surface area (m^2)

CLTD = Cooling Load Temperature Difference

Heat gain through glass by solar radiation(Q)

$$Q = A * SHGFmax * SC * CLF --------2$$

$SHGF_{max}$ = Maximum solar heat gain factor (W/m^2)

SC = Shading coefficient depends on the type of shading

CLF = Cooling load factor

B. Materials and Methods

I. Material

There are three types of PCM. Such as Organic, Inorganic and Eutectic. Organic PCM has additional latent heat capacity, appropriate phase-transition temperature and stable physical and chemical characteristics. Thermodynamic properties, chemical properties, economic properties and kinetic. Good thermal conductivity is required to absorb and release the heat effectively.

Methyl palmitate was selected as the PCM because it has a melting point of 29°C.

II. Method

Selecting a suitable place for the experiment

When choosing a suitable room, it is necessary to consider the window-to-wall ratio, the direction of the windows, the orientation of the room and the sources of internal heat gain. The selected room was at the University of Moratuwa, Sri Lanka. It had a 27% window-wall ratio. Therefore, the room has better natural light performance. The lack of human presence in the room. Therefore, the use of electricity within the room was less. With that internal heat gain can be considered as constant.

Fixing Temperature Sensors to Obtain Indoor Temperature

Calibrated data loggers were placed on the 1.8m above the floor level, facing the zone area and away from any direct sunlight or heat sources.

Testing Chambers Development

3 identical chambers were prepared to a 1:18 scale of the selected room. Figure 1 shows the prepared chambers. These chambers were placed in the selected room.

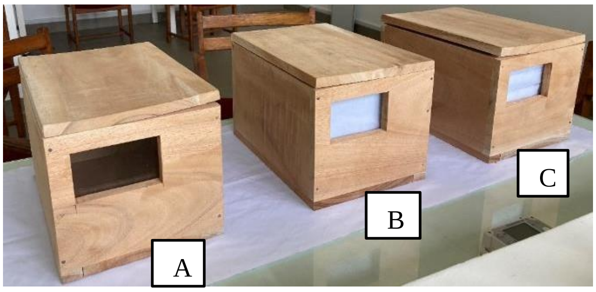

Fig.1- Chambers for testing

Chamber A - represents the room without any curtain material.

Chamber B – represents the room after applying a regular curtain material.

Chamber C - represents the room after applying the developed curtain material using the same fabric that was used in Chamber B.

Prototype development

Fabric pockets were made for macro-scale incorporation of PCM into the curtain. Then 10ml of PCM was inserted into aluminum foil laminated with polyethylene (PE). Sealing of the PCM was done using Aluminum foil and polyethylene. Al foil was selected based on the heat transfer properties of Aluminum.

Fig.2- Top view of the PCM insert curtain applied Chamber

Data collection

Four HOBO U12-012 data loggers were placed to measure temperature. All the chambers were placed in front of the window of the room to expose them to sunlight. Data was taken from the 24th of July to the 29th of July 2024.

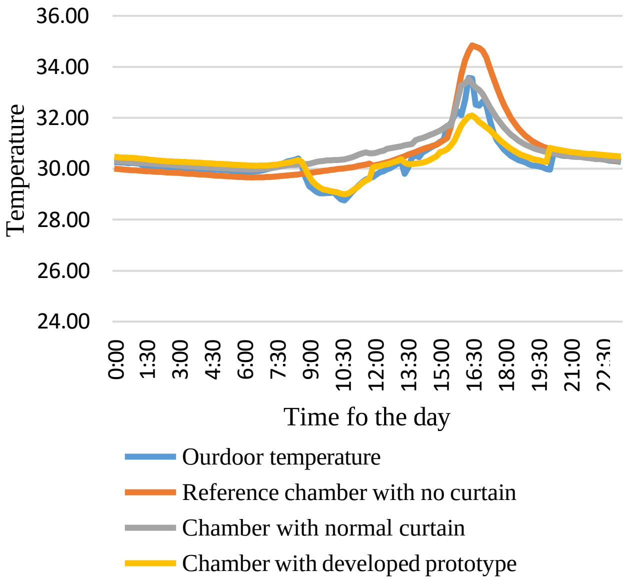

Fig.3 - Temperature vs Time of the day

Cooling load calculation for chambers.

Cooling loads for chambers were calculated using the air mass within the chamber.

III. Results and Discussion

By considering temperature curves, the outdoor temperature was higher than the indoor temperature from 1000hrs to 1700 hrs. Temperature differs from 27.1°C to 31.2°C within a one-month period.

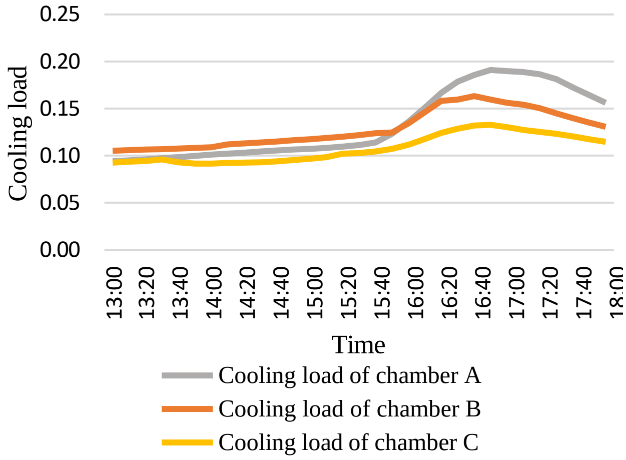

Figure 4 - Cooling load vs Time of chambers after 1400hrs

IV. Conclusion

PCM-based curtains offer a practical and advanced approach to lowering cooling loads in tropical buildings, with the potential to save a significant amount of energy and enhance indoor comfort. The results of this study indicate that PCM-based heat-controlling solutions may be essential in reducing the energy requirements of tropical regions as the world shifts to more environmentally friendly and energy-saving building designs. To fully utilize the potential of PCM-based curtains in practical applications, further study is needed, especially in the fields of PCM encapsulation and long-term testing.

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