NanoWorld Journal

https://doi.org/10.17756/nwj.2023-s1-078

Research Article

Open Access

Thermal Performance of Hollow Acrylic Sheet Integrated with Thermal Energy Storage in Tropical Climate

Gazala Ameen, Pushpendra Kumar Singh Rathore[*], Manglesh Kumar Gupta and Aman Kumar Pal

Centre for Advanced Studies, Lucknow, Uttar Pradesh, India

[*]Correspondence to:
Pushpendra Kumar Singh Rathore
Centre for Advanced Studies,
Lucknow, Uttar Pradesh, India.
E-mail: rathoresamurai@gmail.com

Received: November 24, 2022
Accepted: April 20, 2023
Published: April 22, 2023

Citation: Ameen G, Rathore PKS, Gupta MK, Pal AK. 2023. Thermal Performance of Hollow Acrylic Sheet Integrated with Thermal Energy Storage in Tropical Climate. *NanoWorld J* 9(S1): S403-S407.

Copyright: © 2023 Ameen et al. This is an Open Access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CCBY) (http://creativecommons.org/licenses/by/4.0/) which permits commercial use, including reproduction, adaptation, and distribution of the article provided the original author and source are credited.

Published by United Scientific Group

Abstract

Continuous increment in global energy consumption increases global warming and unwanted climatic changes. Around one-third of global energy is consumed in the building sector, whose major portion is used for space cooling. Thermal energy storage systems with the help of phase change material (PCM) are the most effective technology in the field of development of passive solutions to reduce building space cooling consumption by improving indoor temperature profile of the building. In this study incorporation of thermal energy storage system by shape stabilized PCM in hollow acrylic multiwall polycarbonate sheet with and without fine graphite powder is investigated. A comparative study in comparison with reference hollow acrylic multiwall polycarbonate sheet is prepared for thermal performance investigation in terms of peak temperature reduction, thermal amplitude, time lag, and decrement factor. Sheet which is incorporated with shape stabilized PCM mixed with 5% fine graphite powder shows peak temperature reduction of 10.16 °C, thermal amplitude reduction of 27.08%, decrement factor of 0.750, and time lag of 110 min in comparison with reference acrylic sheet.

Keywords

Thermal energy storage, Phase change material, Buildings

Introduction

In the current energy scenario, world total energy consumption is increasing rapidly due to population increment and improvement in lifestyle of human beings. The world's total energy consumption increased by 140% between 1973 - 2019 [1]. The building sector contribution is around 36% of world's total energy consumption [2]. In India, building sector consumes huge amount of energy, the share of buildings in total national energy consumption is around 38% [3]. In buildings energy consumption, most of the energy is consumed in space cooling and thermal comfort improvement [4]. To reduce energy consumption, which is mostly used in space cooling, incorporation of thermal energy storage system in building envelope is an efficient and popular method form last two decades. Incorporation of thermal energy storage system with latent heat storage capacity increases the thermal energy storage capacity of the building and reduces the thermal fluctuations inside of the buildings [5].

A thermal energy storage system is a passive technology in which material will store heat and cold when difference of temperature is developed. Latent thermal energy storage with the help of PCM can store large amounts of heat energy during phase transition (solid to liquid and liquid to solid). In the development of thermal efficient building envelope thermal energy storage by PCM is incorporated by various methods like - macroencapsulation, microencapsulation, and shape stabilization [6]. Most of the research in the field of building passive thermal comfort is carried out by directly or indirect incorporation of thermal energy storage system in building envelopes. Direct incorporation of thermal energy storage system in building envelope decreases the strength of the envelope as well as decreases lifecycle of the envelope.

A numerical analysis [7] in which a 2 cm PCM wall thickness is expected to have good thermal performance. There are 18 different varieties of PCM used in this study to evaluate the wall's thermal performance. The results demonstrate that putting PCM on the wall may cut cooling power by up to 33% while achieving maximum and minimum heat transfer reductions of 27% and 5%, respectively. A numerical study [8] is conducted on PCM integrated wallboard with software to check thermal inertial in buildings with different PCM thicknesses. The results can indicate wallboards with PCM thickness of 1 cm can allow a doubling the thermal inertia and reduces thermal fluctuations of the buildings. In contrast to ordinary concrete without PCMs, a novel revolutionary concrete with PCM on thermal aspects was explored [9], which demonstrated how the energy storage in the walls by encapsulating PCMs led to lower interior temperatures as well as increased thermal inertia. Researchers have also been interested in PCM embedded floors and chilled ceilings [10]. A numerical study on PCM integrated into the floor was published, and a hydronic radiant ceiling system was employed as the energy discharge system.

This study investigates the thermal energy storage system with shape stable phase change material in hollow acrylic multiwall polycarbonate sheet (HAS) for indoor thermal comfort in HAS sheds. HAS can be developed in various designs and colors. HAS included with thermal energy storage system can also be used for indoor ceiling designing and decoration purpose with the advantage of indoor passive thermal comfort. The shape stable PCM is developed by bentonite clay. Bentonite clay is mostly used for skin protection and medicinal purposes.

Materials and Methods

HAS are widely used to develop lightweight roof structures in buildings. The methodology of this work is to develop a passive solution for HAS for intrinsic thermal comfort. The HAS sheets were filled with shape stable PCM to test the thermal performance of HAS in the actual outdoor subtropical climate. HAS also been tested with 5% and 10% fine graphite powder which increases the heat transfer rate of SSPCM (Shape Stabilized Phase Change Material). The four HAS sheets of shame dimensions were taken in which three sheets were filled with SSPCM with 0%, 5%, and 10% of fine graphite powder and one sheet is reference without any material filling. Table 1 gives information related to methodology of the work. The outer dimension of HAS is 180 mm in length, 180 mm in breath, and height is 20 mm. The dimensional and filling material information and quantity is shown in table 1.

To develop SSPCM, two PCMs of polyethylene glycol and lauric acid have been procured from Otto Chemie Pvt Ltd, Mumbai and bentonite powder is procured from the market. HAS sheet procured from Tilara Polyplast Pvt Ltd, Gujarat. The material of bentonite clay, fine graphite powder, PCM, and HAS are shown in figure 1.

To develop SSPCM, initially two PCM, lauric acid and polyethylene glycol, are mixed and heated on hot plate at 100 °C in 50:50 ratio. After complete mixing eutectic mixture is ultrasonicated in ultrasonicator for one hour at 80 °C. The bentonite clay was initially heated to 125 ˚C to properly mix the eutectic mixture of the phase change material to form the SSPCM. SSPCM with eutectic mixtures of different weight percentages 40 wt%, 50 wt%, 55 wt%, 60 wt%, 65 wt%, 70 wt%, and 75 wt% were tested on a hotplate at 45 °C for 20 min. Bentonite clay mixed with 70 wt% eutectic PCM shows superior PCM holding capacity without any leakage and 75 wt% eutectic PCM shows leakage during hot plate testing as shown in figure 2. For the preparation of experimental passive HAS for thermal comfort of indoor buildings, SSPCM has been used to fill HAS to avoid any PCM phase change leakage. The SSPCM is loaded into HAS with a mixture of 0 wt%, 5 wt% and 10 wt% fine graphite powders to test the thermal performance of HAS at different heat transfer rates. Experimental HAS with and without graphite powder is shown in figure 3.

Figure 1: Material **(a)** Bentonite clay, **(b)** Fine graphite powder, **(c)** PCM- Lauric acid and polyethylene glycol, and **(d)** HAS.

Table 1: Experimental HAS dimensioning and quantity.

Types of sheets	Dimension (mm)	Filling material	Quantity of SSPCM (g)	Quantity of Graphite (g)	Graphite percentage (%)
HAS	180 x 180 x 20	Air	00	00	00
HAS-SSPCM	180 x 180 x 20	SSPCM	400	00	00
HAS-SSPCM-G5	180 x 180 x 20	SSPCM-G5	380	20	5
HAS-SSPCM-G10	180 x 180 x 20	SSPCM-G10	360	40	10

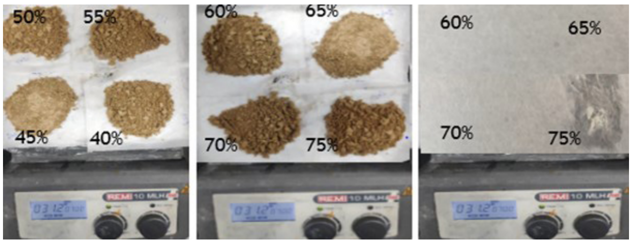

Figure 2: Testing of bentonite clay SSPCM at different weight percent of eutectic PCM.

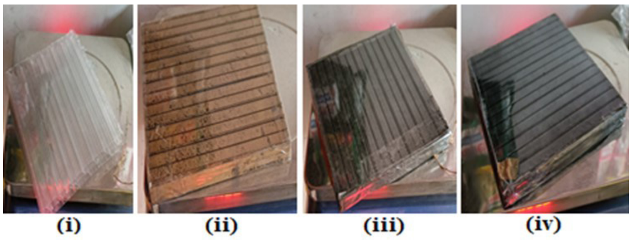

Figure 3: Developed experimental HAS, **(a)** Reference HAS, **(b)** HAS-SSPCM, **(c)** HAS-SSPCM-G5, and **(d)** HAS-SSPCM-G10.

Experimental setup

Experimental setup of four HAS square sheets was developed on the roof of Center for Advanced Studies, AKTU Lucknow which is located in sub-tropical region real climatic condition. Figure 4 shows schematic of HAS and experimental setup developed for the study. The experimental setup of four HAS sheets, (i) HAS, (ii) HAS-SSPCM, (iii) HAS-SSPCM-G5, and (iv) HAS-SSPCM-G10, has been developed in such a way that only the outer surface is exposed to solar energy as shown in figure 5. The other sides are insulated with thick insulation sheets to check the thermal performance and to compare different types of HAS.

To record the thermal difference between the outer surface and the inner surface of the HAS, a J-type thermocouple was installed on the inner and outer surface of the sheet with an accuracy of ±0.5 °C and simultaneously a thermocouple wire was inserted to record the indoor surface temperature for three consecutive days using 16 channel Masibus datalogger in the month of May 2022.

Results and Discussion

To evaluate the pore size of the bentonite clay Brunauer-Emmett-Teller (BET) analysis was done. The BET adsorption and desorption isotherms of bentonite clay are shown in figure 6. The bentonite clay used has a surface area of 1.7 m^2/g and an average pore size diameter of 2.9 nm. These values show that bentonite is a mesoporous material used.

The developed experimental macroencapsulated HAS filled with SSPCM, SSPCM-G5, and SSPCM-G10 to enhance inside thermal comfort inside of HAS. Various thermal performance parameters such as peak temperature reduction, thermal amplitude, time lag, and decrement factor were evaluated. The three days recorded inside temperature profile of reference HAS, HAS-SSPCM, HAS-SSPCM-G5, and HAS-SSPCM-G10 as shown in figure 7.

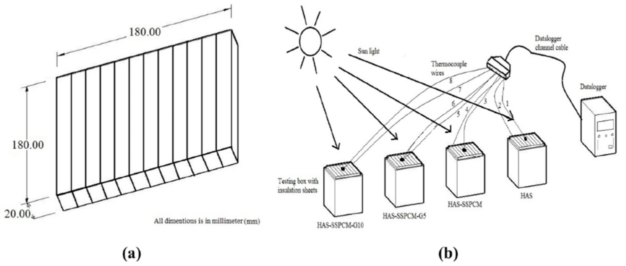

Figure 4: **(a)** Schematic of HAS and **(b)** Schematic of experimental setup of HAS, HAS-SSPCM, HAS-SSPCM-G5, and HAS-SSPCM-G10.

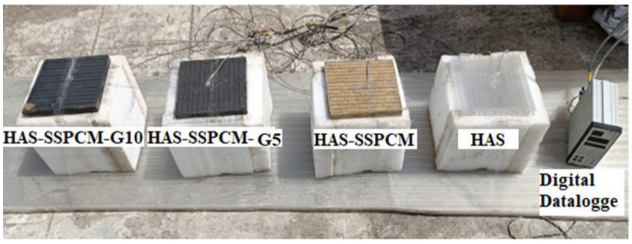

Figure 5: Experimental setup of HAS, HAS-SSPCM, HAS-SSPCM-G5, and HAS-SSPCM-G10.

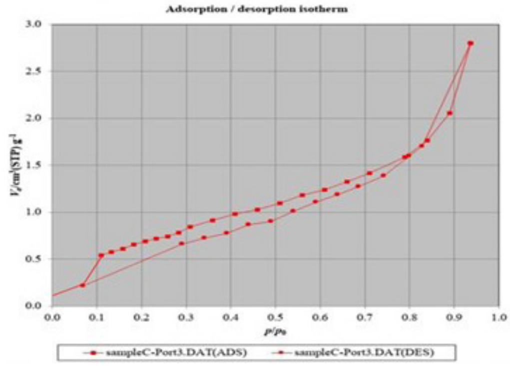

Figure 6: BET adsorption and desorption curve.

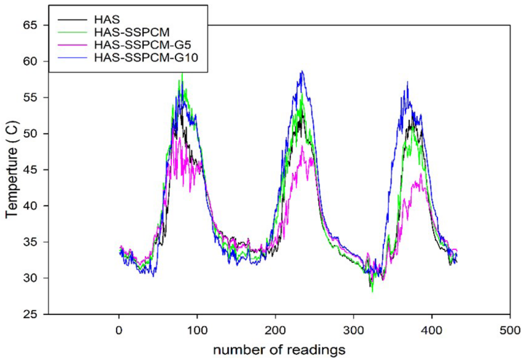

Figure 7: Comparison graph of HAS, HAS-SSPCM, HAS-SSPCM-G5, and HAS-SSPCM-G10.

Peak temperature plays an important role in building inside energy consumption, it shows the maximum energy consumption hours of the building. Peak temperature reduction is a very primary thing in any building energy demand reduction research. The average peak temperature reduction is evaluated in HAS which is embedded with SSPCM-G5 which is 10.16% as compared to reference HAS as shown in table 2.

Table 2: Average peak temperature reduction comparison with reference HAS.

HAS	Day 1 Peak inside surface temperature	Day 2 Peak inside surface temperature	Day 3 Peak inside surface temperature	Peak average inside surface temperature	Reduction in average peak temperature	Reduction in average peak temperature
	(°C)	(°C)	(°C)	(°C)	(°C)	(%)
HAS	54	53.5	53.2	53.57	00	00
HAS-SSPCM-G0	58.7	55.7	51	55.13	-1.56	-2.92
HAS-SSPCM-G5	51.5	48.4	44.5	48.13	5.44	10.16
HAS-SSPCM-G10	57.2	58.7	57.2	57.7	-4.13	-7.71

Thermal amplitude or temperature swing is the measure of maximum and minimum temperature difference of single side of the envelope in 24 hours. Thermal amplitude should be lower for better thermal comfort in the case of building envelopes. The maximum percentage of thermal amplitude reduction is calculated 27.08% as shown in table 3.

In thermal efficient building envelope calculations lower decrement factor indicates the better thermal comfort performance of the material. The decrement factor analysis results are shown in table 4. Calculation of time lag and decrement factor analysis is done by equations 1and 2.

$$Decrement\ factor = \frac{T_{i\max} - T_{i\min}}{T_{o\max} - T_{o\min}} \tag{1}$$

$$Time\ lag = t_{i_{\max}CB} - t_{i_{\max}MB} \tag{2}$$

Where, $T_{i\,max}$ is the inside surface maximum temperature, $T_{i\,min}$ is the inside minimum temperature, $T_{o\,max}$ is the outside surface maximum temperature, $T_{o\,min}$ is the outside minimum temperature, $t_{i_{\max}HAS}$ inside surface peak time of peak temperature of reference HAS and $t_{i_{\max}M-HAS}$ inside surface peak time of peak temperature of modified HAS sheets [11]. HAS-SSPCM-G5 shows the highest time lag 110 min of peak temperature in comparison with HAS-SSPCM and HAS-SSPCM-G10. Time lag graph of all developed experimental sheets are shown in figure 8.

Conclusion

An experimental comparative study of HAS with SSPCM with and without graphite powder is conducted to check thermal performance of HAS with latent thermal

Table 3: Thermal amplitude analysis in comparison with reference HAS.

HAS	Three days inside HAS surface average maximum temperature	Three days inside HAS surface average minimum temperature	Thermal amplitude	Reduction in thermal amplitude
	(°C)	(°C)	(°C)	(%)
HAS	53.57	30.9	22.67	0
HAS-SSPCM-G0	55.13	30.6	24.53	-8.21
HAS-SSPCM-G5	48.13	31.6	16.53	27.08
HAS-SSPCM-G10	57.7	30.7	27	-19.10

Table 4: Decrement factor analysis.

HAS	Three days outside HAS surface average maximum temperature	Three days outside HAS surface average minimum temperature	Thermal amplitude of outside surface of the HAS	Three days inside HAS surface average maximum temperature	Three days inside HAS surface average minimum temperature	Thermal amplitude of inside surface of the HAS	Decrement factor
HAS	57.6	30.43	27.17	53.57	30.9	22.67	0.834
HAS-SSPCM-G0	56.07	29.77	26.3	55.13	30.6	24.53	0.933
HAS-SSPCM-G5	52.80	30.76	22.04	48.13	31.6	16.53	0.750
HAS-SSPCM-G10	58.93	30.53	28.4	57.7	30.7	27	0.951

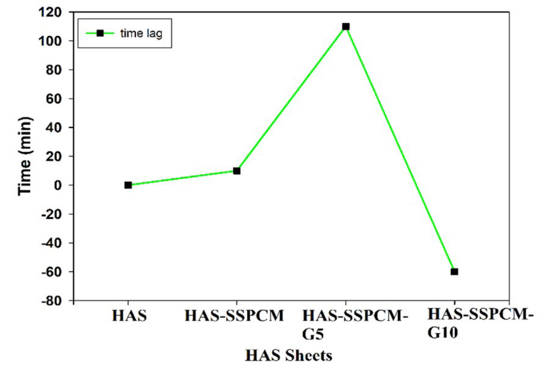

Figure 8: Time lag graph.

heat storage capacity. Four developed sheets are as follows (i) HAS, (ii) HAS-SSPCM, (iii) HAS-SSPCM-G5, and (iv) HAS-SSPCM-G10. Various comparative calculations like peak temperature reduction, thermal amplitude, time lag, and decrement factor were analyzed in comparison with reference HAS.

- Among all developed sheets HAS-SSPCM-G5 gives better thermal comfort parameters.
- The average peak temperature reduction of -1.56 °C, 5.44 °C, and -4.13 °C were recorded by HAS-SSPCM, HAS-SSPCM-G5, and HAS-SSPCM-G10, respectively.
- Inside thermal amplitude of -8.21%, 27.08%, and -19.10% was calculated in comparison to the reference HAS by HAS-SSPCM, HAS-SSPCM-G5, and HAS-SSPCM-G10. respectively.
- HAS-SSPCM-G5 showed the highest time lag 110 min of peak temperature in comparison with HAS, HAS-SSPCM, and HAS-SSPCM-G10.

Acknowledgments

The authors would like to thank Centre for Advanced Studies for providing resources to carry out this research.

Conflict of Interest

The authors declare no conflict of interests that are relevant to the content of this article.

Credit Author Statement

Gazala Ameen: Conceptualization, Methodology, Data curation; Pushpendra Kumar Singh Rathore: Writing - original draft preparation, Writing - review and editing, Supervision; Manglesh Kumar Gupta: Visualization, Investigation; Aman Kumar Pal: Investigation, Writing - review and editing. All the authors read and approved the manuscript.

References

1. Key World Energy Statistics 2021. [https://www.iea.org/reports/key-world-energy-statistics-2021] [Accessed April 21, 2023]
2. Global Status Report for Buildings and Construction 2020. [https://globalabc.org/resources/publications/2020-global-status-report-buildings-and-construction] [Accessed April 21, 2023]
3. India Energy Outlook 2021. [https://www.iea.org/reports/india-energy-outlook-2021] [Accessed April 21, 2023]
4. Khosla R, Agarwal A, Sircar N, Chatterjee D. 2021. The what, why, and how of changing cooling energy consumption in India's urban households. *Environ Res Lett* 16(4): 044035. https://doi.org/10.1088/1748-9326/abecbc
5. Hassan F, Jamil F, Hussain A, Ali HM, Janjua MM, et al. 2022. Recent advancements in latent heat phase change materials and their applications for thermal energy storage and buildings: a state of the art review. *Sustain Energy Technol Assess* 49: 101646. https://doi.org/10.1016/j.seta.2021.101646
6. Rathore PKS, Gupta NK, Yadav D, Shukla SK, Kaul S. 2022. Thermal performance of the building envelope integrated with phase change material for thermal energy storage: an updated review. *Sustain Cities Soc* 79: 103690. https://doi.org/10.1016/j.scs.2022.103690
7. Nariman A, Kalbasi R, Rostami S. 2021. Sensitivity of AHU power consumption to PCM implementation in the wall-considering the solar radiation. *J Therm Anal Calorim* 143: 2789-2800. https://doi.org/10.1007/s10973-020-10068-4
8. Kuznik F, Virgone J, Noel J. 2008. Optimization of a phase change material wallboard for building use. *Appl Therm Eng* 28(11-12): 1291-1298. https://doi.org/10.1016/j.applthermaleng.2007.10.012
9. Cabeza LF, Castellon C, Nogues M, Medrano M, Leppers R, et al. 2007. Use of microencapsulated PCM in concrete walls for energy savings. *Energy Build* 39(2): 113-119. https://doi.org/10.1016/j.enbuild.2006.03.030
10. Belmonte JF, Eguía P, Molina AE, Almendros-Ibáñez JA. 2015. Thermal simulation and system optimization of a chilled ceiling coupled with a floor containing a phase change material (PCM). *Sustain Cities Soc* 14: 154-170. https://doi.org/10.1016/j.scs.2014.09.004
11. Asadi I, Hashemi M, Sajadi B, Mahyuddin NB, Baghban MH, et al. 2023. Evaluating the time lag and decrement factor of mortar and concrete containing OPBC as an agricultural by-product lightweight aggregate. *Case Studies Therm Eng* 41: 102609. https://doi.org/10.1016/j.csite.2022.102609