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RESUME

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1. OBJECTIVES

- To strive for academic excellence and impart quality education with emphasis on outcome based teaching-learning approach and problem-based learning approach.
- To improve teaching-learning pedagogy through Bloom's Taxonomy model which having following hierarchical levels of skills: Remember, Understand, Apply, Analyze, Evaluate and, Create.
- To work for a reputed organization which will give me a platform to take a big leap in the research and development.
- To develop new laboratories and research centers which will boost the outcome of R&D in terms of patents, funded projects, national and international collaboration and consultancy for the benefit of society and Industries.

2. ACADEMIC QULIFICATION

- PhD from Indian Institute of Technology (BHU) in Thermal Energy Storage in 2021.
- M.Tech. in Mechanical Engineering in 2013 (Bronze medalist).
- B.Tech in Mechanical Engineering in 2008 with 1st division.
- Intermediate in 2004 from CBSE Board with 1st division.
- Highschool in 2002 from CBSE board with 1st division.

3. ACADEMIC EXPERINCE

- Assistant Professor in GLA University, Mathura (NAAC 'A' grade) from 21/06/2008 to 30/12/2018 at AGP 7000/- of 6th pay commission.

- **Courses taught**
    1. Internal Combustion Engine
    2. Thermal Engineering
    3. Energy conversion and management
    4. Renewable Energy Technologies
    5. Solar Energy Engineering

4. RESEARCH EXCELLENCE

- **Articles in SCI/SCIE indexed International Journal (58.28 Impact factor of research publications)**

1. Rathore, P. K. S., & Shukla, S. K. (2021). Enhanced thermophysical properties of organic PCM through shape stabilization for thermal energy storage in buildings: A state of the art review. *Energy and Buildings*, 110799. **Impact Factor 4.86.**
2. Gupta, N. K., Sharma, A., Rathore, P. K. S., & Verma, S. K. (2020). Thermal performance optimization of heat pipe using nanofluid: response surface methodology. *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, *42*(11), 1-16. **Impact Factor 1.18.**
3. Chauhan, V. K., Shukla, S. K., Tirkey, J. V., & Rathore, P. K. S. (2020). A comprehensive review of direct solar desalination techniques and its advancements. *Journal of Cleaner Production*, 124719. **Impact Factor 7.24.**
4. Rathore, P. K. S., Shukla, S. K., & Gupta, N. K. (2020). Yearly analysis of peak temperature, thermal amplitude, time lag and decrement factor of a building envelope in tropical climate. *Journal of Building Engineering*, *31*, 101459. **Impact Factor 3.37.**
5. Rathore, P. K. S., Shukla, S. K., & Gupta, N. K. (2020). Synthesis and characterization of the paraffin/expanded perlite loaded with graphene nanoparticles as a thermal energy storage material in buildings. *Journal of Solar Energy Engineering*, *142*(4). **Impact Factor 1.19.**
6. Rathore, P. K. S., & Shukla, S. K. (2020). An experimental evaluation of thermal behavior of the building envelope using macroencapsulated PCM for energy savings. *Renewable Energy*, *149*, 1300-1313. **Impact Factor 6.2.**
7. Rathore, P. K. S., Shukla, S. K., & Gupta, N. K. (2020). Potential of microencapsulated PCM for energy savings in buildings: A critical review. *Sustainable Cities and Society*, *53*, 101884. **Impact Factor 5.26.**
8. Gupta, N. K., Verma, S. K., Rathore, P. K. S., & Sharma, A. (2020). EFFECTS OF CuO/WATER NANOFLUID APPLICATION ON THERMAL PERFORMANCE OF MESH WICK HEAT PIPE. *Heat Transfer Research*, *51*(9). **Impact Factor 1.19.**

9. Rathore, P. K. S., & Shukla, S. K. (2019). Potential of macroencapsulated PCM for thermal energy storage in buildings: A comprehensive review. *Construction and Building Materials*, *225*, 723-744. **Impact Factor 4.41.**
10. Rathore, P. K. S., Chauhan, D. S., & Singh, R. P. (2019). Decentralized solar rooftop photovoltaic in India: On the path of sustainable energy security. *Renewable energy*, *131*, 297-307. **Impact Factor 6.2.**
11. Gupta, N. K., Tiwari, A. K., Verma, S. K., Rathore, P. K. S., & Ghosh, S. K. (2019). A comparative study of thermal performance of a heat pipe using water and nanofluid, and a nanoparticle-coated wick heat pipe using water. *Heat Transfer Research*, *50*(18). **Impact Factor 1.19.**
12. Rathore, P. K. S., Das, S. S., & Chauhan, D. S. (2018). Perspectives of solar photovoltaic water pumping for irrigation in India. *Energy strategy reviews*, *22*, 385-395. **Impact Factor 3.89.**
13. Rathore, P. K. S., Rathore, S., Singh, R. P., & Agnihotri, S. (2018). Solar power utility sector in india: Challenges and opportunities. *Renewable and Sustainable Energy Reviews*, *81*, 2703-2713. **Impact Factor 12.1.**

- **Conference proceedings and Chapters in peer reviewed books (International/National)**

1. H. sawarn, S.K. Shukla , P.K.S. Rathore. (2020). Development in Solar Cooking Technology in the Last Decade: A Comprehensive Review. International Conference on Futuristic and Sustainable Aspects in Engineering and Technology (FSAET-2020), GLA University. **Selected for publication in IOP Conference Series materials science and engineering. Scopus Indexed.**
2. H. sawarn, P.K.S. Rathore, S.K. Shukla. (2020). Techno-Economic feasibility analysis of parabolic solar cooker in tropical environment India. 2nd International conference on future learning aspects of mechanical engineering, Amity university. **Selected for publication in Springer Nature, Singapore. Scopus Indexed.**
3. Shukla, S. K., & Rathore, P. K. S. (2020). Production of biodiesel and its application in engines. *Waste Biorefinery: Integrating Biorefineries for Waste Valorisation*, 379. **Published by Elsevier**. **Scopus indexed**.
4. N. K. Gupta, P. S. Rathore and S. Sinha, "Biodiesel production from waste cooking oil using ultrasonic cavitation & its characteristics," *2017 International Conference on Advances in Mechanical, Industrial, Automation and Management Systems (AMIAMS)*, Allahabad, 2017, pp. 139-143. **Available on IEEE Explore. Scopus indexed**.
5. Rathore P.K.S. (2019) An Experimental Study On Solar Water Heater Integrated With Phase Change Material. In: Saha P., Subbarao P., Sikarwar B. (eds) Advances in Fluid and Thermal Engineering. Lecture Notes in Mechanical Engineering. **Springer, Singapore. Scopus Indexed**
6. Rathore PK. Technological Evaluation of Enhancing Thermal Energy Storage in Buildings Using PCM. Proceedings of the International Conference on Smart Technologies for Green and Sustainable Future, **NIT Bhopal**, 2017, Pages 260-265, **ISBN 978-81-909984-9-9**

7. Rathore PK, Srivastava S, Gupta NK. Solar energy in India: Key for sustainable development. Proceedings of the International Conference on Frontiers in Engineering, Applied Sciences and Technology, **NIT Tiruchurapalli**, 2017, Pages 22-27, **ISBN 978-81-908388-8-7.**
8. Rathore PK, Rathore S. Solar power profile of India: on the path of sustainable development. Proceedings of the National Conference on Energy, **NIT Calicut**, 2016.
9. Rathore PK, Tripathi RN. Performance analysis of 2-stroke gasoline engine by using compressed air. Proceedings of International conference on Industrial Engineering Science and Applications, **NIT Durgapur**, 2014, Pages 177-181, **ISBN 978-93-80813-27-1**.
10. Rathore PK, Rathore S. Performance Analysis of a 2-Stroke Compressed Ignition Engine by Using Compressed Air. Proceedings of International conference on Recent Advances in Mechanical Engineering and Interdisciplinary Developemnts, **IEEE**, 2014, Pages 143-147, **ISBN 978-1-4799-3158-3**.
11. Rathore PK, Singh MP, Agnihotri S. Performance Study of Diesel Engine by using Mahua Methyl Ester (biodiesel)and its Blends with Diesel Fuel. International Journal of System and Algorithm, Volume 3, Issue ICRASE 13, 2013, Pages 111-114, **ISSN 2277-2677**.
12. Shukla SK, Singh T, Rathore PK. Comparative Analysis of Plate Type and Fin Tube Type Heat Exchanger for Organic Rankine Cycle. Proceedings of National conference on emerging materials and nanotechnology, 2019, S. S. P. Mandal’s Chandmal Tarachand Bora College of Arts, Commerce and Science, Pune.

➢ **Funded projects undertaken**

1. Mentoring a NSTEDB, **Department of Science and Technology, Government of India** sponsored project of cost **Rs. 2.5 Lakh** under the aegis of IEDC in 2018 on Solar Thermal Energy Storage.
2. Mentor of GLA University funded project of Design & Development of All Terrain Vehicle (ATV) in the year 2015, 2016 and 2017.

➢ **Reviewer of International journals**

1. Journal of Cleaner Production, Elsevier (SCIE Journal)
2. Renewable and Sustainable Energy Reviews, Elsevier (SCIE Journal)
3. Energy Reports, Elsevier (SCIE Journal)
4. Energy & Environment, Sage publication (SCIE journal)
5. Energy, Sustainability and Society, Springer (SCIE journal)
6. RSC Advances, Royal Society of Chemistry (SCIE Journal)
7. Journal of Advanced Research in Fluid Mechanics and Thermal Sciences (Scopus)
8. International Journal of Energy Research, John Wiley & Sons (SCIE Journal)
9. AIP Advances, American Institute of Physics (SCIE Journal)
10. Energy Sources, Part B: Economics, Planning, and Policy, Taylor & Francis (SCI Journal)
11. Building Simulation, Springer (SCIE Journal)

5. ACADEMIC EXCELLENCE

➢ Workshop/Conferences/Summer/Winter school attended

1. A one week TEQIP-III sponsored short term course on "Advanced Nanostructured Materials for Sustainable Energy and Environmental Remediation -Tiny Particles, Big Effects" from 18/12/2020 to 22/12/2020 organized by the Department of Chemical Engineering & Department of Chemistry, **MNIT, Jaipur**, Rajasthan.
2. A 6 day online AICTE approved quality improvement program-short term course on "Energy and environment management for sustainable development" organized by Department of Mechanical Engineering of **IIT (BHU)** from 07-12 Dec, 2020.
3. A 5 day short term training program on "Challenges and Opportunities in Designing Nanoarchitectonics of Nanoporous Carbon Materials for Industrial Applications" organized by the department of Materials and Metallurgical Engineering of **MANIT, Bhopal** from 16th September, 2020 to 20th September, 2020.
4. A 3 day **Indo-UK workshop** on "Valorisation of Agri-Waste for Energy and Nutrient Recovery" organized by the department of Mechanical Engineering of **IIT (BHU)**, Varanasi from 15th January to 17th January 2020.
5. A 6 day workshop on "Energy Efficiency in Harmony With Environment" organized by the department of Mechanical Engineering of **IIT (BHU)**, Varanasi from 29th October to 3rd November 2018.
6. A 5 day short term course on "Energy Management" organized by **IIT Bombay** from 19th November to 23rd November 2017.
7. A 3 day workshop organized by MSME on "Lean Six sigma Yellow belt: Quality improvement and problem solving techniques" at GLA University, Mathura from 28th April to 30th April 2017.
8. A 6 day workshop on "Solar Power Projects Development" at **MNIT Jaipur** on September, 2015.
9. A faculty development program conducted by INFOSYS on December 2008 at GLAITM, Mathura

➢ Administrative responsibilities

Position held	Period
Training and Placement advisor	January 2010 – December 2018
Project in charge	July 2009 – April 2011
Lab In-charge of Automobile Engg. Lab	December 2009 – December 2018
SAE Faculty Advisor of the University	July 2015 – December 2017
Lab setup and lab in-charge of center of automotive research	July 2016 – December 2018

- **Guest speaker/Session chair/Editorial board member/Membership of socities etc.**

1. Session chair in an International Conference on "Futuristic and Sustainable Aspects in Engineering and Technology (FSAET-2020) organized by Department of Mechanical & Civil Engineering, GLA University, Mathura held on 18-19 Dec, 2020.
2. Invited talk delivered in QIP-STC on "Energy and Environment Management For Sustainable Developeement" held in Department of Mechanical Engineering, IIT(BHU) on the topic "Building Ingtegrated Solar Thermal Energy Storage".
3. Editorial board member of the International Journal of Sustainable and Green Energy published by the Science Publishing Group, USA.

6. AWARDS/HONORS/ACHIEVEMENTS

1. Recipient of the Research Excellence Award 2019 by Institute of Scholars (InSc).
2. Bronze Medalist in M.Tech.

PERSONAL DETAILS

Father's Name:	Mr. Naresh Chandra Singh Rathore
Date of Birth and Age:	05.05.1987, & 34 Yrs.
Gender:	Male
Citizenship:	Citizen of India
Religion:	Hindu
Marital Status:	Married
Language known:	English and Hindi

Name and address of the reference, not related to the applicant:

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GLA University
Mathura (UP)
E-mail: pdschauhan@gmail.com

(2) Prof. Shailendra Kumar Shukla
Department of Mechanical Engineering
Indian Institute of Technology (BHU), Varanasi
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I certify that the information given above is true, complete and correct to the best of my knowledge and belief.

Signature: Pushpendra Kumar Singh Rathore

Date: 20/04/2021

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Review

Potential of macroencapsulated PCM for thermal energy storage in buildings: A comprehensive review

Pushpendra Kumar Singh Rathore *, Shailendra Kumar Shukla

Department of Mechanical Engineering, Indian Institute of Technology (BHU), Varanasi 221005, India

HIGHLIGHTS

- Potential of Macroencapsulated Phase Change Material for energy savings in buildings is reviewed.
- Macroencapsulation technique of PCM is studied.
- Thermal energy storage and potential PCM for improving indoor thermal behavior of the buildings.
- Challenges were identified and suggestion for future studies was presented.

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ABSTRACT

Advances in thermal energy storage techniques/methods, using Phase Change Material (PCM), have gained much hype among researchers in the last decade. Thermal energy storage systems can significantly reduce energy consumption and promotes the use of renewable sources of energy. In recent decades, the building sector has evolved as one of the major consumer of energy resulting in high levels of carbon emissions. Thermal energy storage combined with PCM is an effective method for improving the energy efficiency of the buildings. PCM can be incorporated in the building envelope in many ways. One of the simplest and effective method of integrating PCM directly in building material is macroencapsulation. This method not only improves the indoor thermal behavior of the buildings, but also reduces the cooling load without or little compromising with the mechanical strength of the building structure. In this article, a critical review of the application of macroencapsulated PCM in buildings for energy savings has been carried out. A detailed review of various approaches to integrate the macroencapsulated PCM in the building envelope has been shown. Effect on indoor thermal behavior and reduction in cooling load was analyzed for different approaches. Additionally, the compatibility of various materials used for making containers for encapsulation was also investigated. A detailed description of macroencapsulation technique, types of thermal energy storage methods used in buildings, suitable PCM available for encapsulation has also been shown in the article.

Contents

Abbreviations: PCM, Phase Change Material; TES, Thermal Energy Storage; LHES, Latent Heat Energy Storage; GNP, Graphene Nanoplatelets; PEG, Polyethylene glycol; HNT, Halloysite nanotube; EG, Expanded graphite; HVAC, Heating Ventilation and Air-conditioning; HDPE, High Density Polyethylene; XPS, Extruded Polystyrene; PVA, Polyvinyl Acetate; HSB, Hollow Steel Ball; EPDM, Ethylene Propylene Diene Monomer; DSC, Differential Scanning Calorimetry; SEM, Scanning Electron Microscope; EDS, energy dispersive X-ray spectrometer.

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Enhanced thermophysical properties of organic PCM through shape stabilization for thermal energy storage in buildings: A state of the art review

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Shape stabilized PCM
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Building
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ABSTRACT

Thermal energy storage using organic Phase Change Material (PCM) can play an important role in effective thermal management of the building. Organic PCM are widely utilized to regulate the indoor thermal environment of the building because of good chemical and thermal stability, high heat of fusion, and large availability in the required temperature range. However, organic phase change material suffers from problems like low thermal conductivity and leakage during phase transition which limits there applicability in buildings. Therefore, the appropriate approach of preparing Shape Stabilized Composite Phase Change Material (ss-CPCM) with high thermal conductivity and no leakage will significantly improve the thermo-physical properties and increases the applicability of the organic PCM in buildings. This review is an attempt to investigate the effectiveness of organic PCM as ss-CPCM with a specific focus on its applicability in regulating the indoor thermal behavior of the buildings. It discusses in brief about thermal energy storage in buildings, PCM with emphasis on organic PCM, and shape stabilized PCM. In details, it analyzes various porous support materials and their effect on thermo-physical properties of organic PCM. Additionally, a detailed investigation of various types of nanoparticles used to enhance the thermo-physical characteristics of ss-CPCM was conducted. The study suggests that ss-CPCM has the potential to improve the thermal conductivity, minimize the leakage, and effectively regulate the indoor temperature by reducing the peak temperature and increasing the time delay. However, reduction in heat storage capacity of ss-CPCM needs to be critically analyzed. Additionally, factors like real time studies in buildings, annual/seasonal analysis, heat management from ss-CPCM during night, and techno-economic analysis of using ss-CPCM in building envelope need to be addressed.

Contents

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Yearly analysis of peak temperature, thermal amplitude, time lag and decrement factor of a building envelope in tropical climate

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ARTICLE INFO

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ABSTRACT

Two similar building structures, one is with macrocapsules of PCM called the experimental building structure (EBS), while the other is without macrocapsules of PCM called the reference building structure (RBS) were developed using conventional construction materials. Both the structures were then monitored for one year in the outdoor tropical type of environmental conditions to evaluate the indoor thermal behavior based on indoor peak temperature, indoor thermal amplitude, time lag, and decrement factor. Additionally, the annual average peak heat flux and corresponding cost-savings in peak cooling load were also analyzed. The results depict that EBS shows a reduction in the indoor peak temperature round the year, ranging from 0.2 °C to 4.3 °C and a percentage reduction in indoor thermal amplitude ranging from -2.43% to 51.3%. The annual average time delay of 97.5 min and the annual average percentage reduction of 24.69% in the decrement factor was obtained by the EBS. The annual average peak heat flux reduction of 17.37% and corresponding yearly average cost-saving in peak cooling load of 1.47 rupees/kWh/m^2/day was obtained in the EBS.

1. Introduction

In the 20th-century building sector (residential and commercial) has evolved as a major primary energy consumer. As per International Energy Agency (IEA), more than 1/3rd of the global final energy consumption is on the building sector (both residential and commercial). As a result, it is one of the major sources of carbon dioxide (CO_2) emissions. In some countries, the building sector consumes almost 80% of the total final energy [1]. These figures are staggering and tend to increase at a faster pace in the near future. A major source, of the total end-use of energy in the buildings, is utilized for Space heating and cooling. More than 50% of the total final energy consumption in the buildings comes from space heating and cooling [2]. Thus, Space heating and cooling show a significant potential of reducing energy consumption in the buildings. Energy-efficient buildings will play a very crucial role in optimizing the demand of energy for space cooling and heating. Various techniques are used to develop energy-efficient building envelope to improve the indoor thermal environment [3,4]. However, enhancing the latent heat storage capacity of the building by incorporating the Phase Change Material (PCM) has attracted many researchers [5,6] and scientists [7] because of their various merits. PCM exhibits high latent heating value, phase change in the desired temperature range, readily available, non-flammable, low cost and good thermal stability [8,9]. Additionally, their energy-saving potential and ease of workability have made their application in the buildings more significant than any other technique/material [10,11].

The PCM when get embedded in the building envelope increases the latent thermal energy storage capacity of the building. It works on the principle that when the temperature of the building envelope increases, because of the increase in solar radiation intensity, the PCM starts melting and the solid-liquid phase transition occurs. The solid-liquid phase transition takes place almost at constant temperature and consequently, a huge amount of heat energy is stored in the PCM. Now when the temperature falls and reaches below the phase transition temperature of the PCM, the liquid-solid phase transition takes place which results in the release of the stored heat [12]. Thus, the PCM can regulate the indoor thermal behavior of the building envelope very effectively by utilizing solar thermal energy. However, PCM suffers from two major drawbacks, i.e. loss due to leakage and low thermal conductivity [13,14]. When the PCM is directly embedded in the building envelope, there are high chances of leakage due to the solid-liquid phase transition. Additionally, the poor thermal conductivity of the PCM may increase the

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Potential of microencapsulated PCM for energy savings in buildings: A critical review

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Microencapsulated Phase Change Material (MPCM)
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ABSTRACT

The building sector, around the world, has shown a tremendous increase in the demand for energy due to economic development, urbanization and improvement in the living standard. A major chunk of this energy is utilized for space cooling and heating. Microencapsulated Phase Change Material (MPCM) based thermal energy storage technology has the potential to reduce the energy consumption of the buildings, by improving the indoor thermal comfort, when integrated directly into the building materials. A large number of research articles have been reported to assess the thermal performance of the building envelope by integrating MPCM in the building materials like cement, mortar, brick, wallboard, and gypsum. This paper shows a comprehensive review of various experimental studies (laboratory-based and real ground testing), using only MPCM, have been done to evaluate the actual potential of MPCM in improving the thermal performance of the buildings. The articles are classified based on characterization, real-time testing with building material like mortar, brick, and cement, real-time testing with lightweight building material like wallboard, plasterboard and gypsum, and computer simulation software of MPCM. Based on the review research gap has been identified and are analyzed for suggesting future research work.

1. Introduction

In the 21st century, the building sector has evolved as one of the largest energy-consuming sector and is equally responsible for carbon dioxide (CO_2) emissions (International Energy Agency, 2013). Global building-related CO_2 emissions and electricity consumption are continuously rising at an average rate of 1% and 2.5% per year respectively since 2010 (International Energy Agency, 2017). The building sector, both residential and commercial, consume more than one-third of the world's final energy. In some regions which are highly dependent on biomass, the energy consumption is as high as 80% (International Energy Agency, 2013). Energy trends in building sector show that a major portion of energy in buildings is utilized for space cooling and heating. More than 20% of the total energy, in buildings, is utilized for space heating and cooling and if this trend continues, then the energy consumption for space cooling and space heating will rise to 50% of the total energy consumed in the building sector respectively up-to 2050 (International Energy Agency, 2018). Fig. 1 shows the prediction of electricity demand in the building sector up-to 2050. Therefore, they represent the largest opportunity to reduce consumption of energy in the building sector.

The building envelope determines the heating and cooling load of a building because they are directly exposed to solar radiation and therefore it must be optimized using energy-efficient and low-carbon technology/solutions (Sadineni, Madala, & Boehm, 2011; Sozer, 2010). A large temperature difference exists in the buildings because of variation in season, day and night as well as the presence of a heat source like machines, computer facilities, and human.

In recent years, the research on developing systems and methods to ensure energy efficiency in buildings has been drastically increased. Energy-efficient buildings will ensure a peak power reduction for space heating and cooling, shifting of peak heating and cooling loads to the non-peak hours or low tariff hours, helps in creating an envelope for the normal indoor temperature and, efficient utilization of passive heating and cooling loads. A novel approach of reducing cooling and heating loads of the buildings, which has gained much interest among researchers, is Thermal Energy Storage (TES) using Phase Change Material (PCM) (Arce, Medrano, Gil, Oró, & Cabeza, 2011; Dincer & Rosen, 2002; Dincer, 2002; Zalba, Marın, Cabeza, & Mehling, 2003). The main property which makes PCM more useful than other materials for thermal energy storage is that it stores heat energy in latent form, because of which it has a greater heat storage capacity per unit volume

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An experimental evaluation of thermal behavior of the building envelope using macroencapsulated PCM for energy savings

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A R T I C L E I N F O

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A B S T R A C T

There is a very significant rise in energy demand of the building sector in developing countries. A major portion of this energy is used for space cooling and heating in buildings. Due to the concern of global warming, energy-efficient solution in buildings is the need of the hour. Increasing the thermal energy storage capacity of the building by using Phase Change Material (PCM) is an innovative technique to reduce the energy demand. This paper evaluates the thermal response of the building envelope integrated with macroencapsulated PCM under real tropical environment. The indoor thermal profile of both the cubicles in terms of peak temperature, time lag, and thermal amplitude was studied. The reduction in cooling load and energy saving in terms of cost/kWh of electricity was also evaluated. The thermography images of both the cubicles were also analyzed to find out the thermal response of the cubicles towards macro-encapsulation. The results show 40.67%–59.79% reduction in thermal amplitude, including 7.19% –9.18% fall in peak temperature of all the walls, the roof and indoor ambient of experimental cubical. Additionally, 60–120 min of time delay along with 38.76% of reduction in cooling load of the experimental cubicle was achieved.

1. Introduction

Due to climate change concerns at the global level, the research on energy-efficient solutions has been increased. The building sector has evolved as one of the major energy-consuming sector in developed and developing countries. As shown in Fig. 1, almost 1/3rd of the total final energy consumption is of the building sector and is also equally responsible for CO_2 emission [1]. A major portion of this energy is used for space cooling and heating in buildings. Cooling energy use in buildings has doubled since 2000, from 3.6 EJ to 7 EJ, making it the fastest growing end-use energy in buildings, led by a combination of warmer temperatures and increased activity due to population and economic growth. If this trend goes on, then more than 50% of the total energy consumed in the buildings will be used for space cooling and heating up to 2050 [2]. Therefore, space cooling and heating represent the largest opportunity of reducing the consumption of energy in the building sector.

Solar thermal energy storage systems using Phase Change Material (PCM), in the building material, is an energy-efficient solution for cooling load reduction. It has gained significance among researchers in recent years as it can control the daily fluctuations in the indoor temperature [3–8] and, as a result, reduces the energy required for space cooling and heating. PCM can store solar thermal energy in the form of latent heat which has the advantage of high energy storage density, storing heat at the constant temperature corresponding to the phase transition temperature and, have 5 to 14 times more energy per unit volume than sensible heat materials [9,10]. The principle of working of the PCM is that it stores energy when melts and releases the energy when solidifies. The melting of the PCM takes place during the daytime when the temperature due to the solar radiation is more than the melting temperature of the PCM. Similarly, solidification of the PCM takes place during the night, when the outside ambient temperature is lower than the melting temperature of the PCM. Hence, when PCM is integrated into the building envelope the heat storage capacity of the building increases and consequently improves the indoor thermal behavior [11].

Incorporation of the PCM in the building envelope can be done by any of the following methods: direct incorporation, immersion, vacuum impregnation, micro-encapsulation, macro-encapsulation, and shape-stabilized PCMs [12]. Out of the above-mentioned techniques, micro-encapsulation, and macro-encapsulation has

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