International Journal of Advanced Technology in Engineering and Science
Vol. No.4, Issue No. 12, December 2016
www.ijates.com
ijates
ISSN 2348 - 7550

APPLICATION OF PHASE CHANGE MATERIALS FOR THERMAL MANAGEMENT OF BUILDINGS: STATE OF THE ART AND REVIEW

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ABSTRACT

The energy efficiency of buildings is today a prime objective for energy policy at regional, national and international levels. This paper aims to explore how and where phase change materials (PCMs) are used in passive latent heat thermal energy storage (LHTES) systems for thermal management of buildings and making them energy efficient. The review presented here reveals how and where PCMs are used in the cooling systems, how are these LHTES systems related to buildings. This paper investigates previous work on thermal energy storage by incorporating phase change materials (PCMs) in the building envelope. The basic principle, candidate PCMs and their thermo physical properties, incorporation methods, thermal analyses of the use of PCMs in walls, floor, ceiling and window etc. are discussed. All studies have shown that the use of PCMs helps to improve energy performance of buildings, the problems were encountered in heat transfer and the amount of PCM needed for storage. These topics are also worthy of further research.

Keywords: Building, Charging, Discharging, LHTES, PCM, Thermal Management

I INTRODUCTION

Thermal energy storage for heating and cooling of buildings is becoming increasingly popular due to the increased use of fossil fuels and environmental concerns [1]. Scientists all over the world are researching on the issue fining new renewable sources and methods of minimizing the use of fossil fuels. Particularly, in extremely cold/hot areas, electrical energy consumption is high for heating and cooling of buildings for human comfort. The current technology of incorporating LHTES into buildings gives enormous opportunity to use solar energy for domestic space heating/cooling [2]. In developed countries buildings account for a 20‑40% of the total final energy consumption, in the European Union this number is at 40% [3] Unfortunately the growing trend of energy use is expected in the future due to climate changes. Use of LHTES devices can minimize the peak demand of electricity

ijates
ISSN 2348 - 7550

for air conditioning systems. LHTES thus allows consumers not only producing cold at a cheaper electricity rate but also installing equipment of smaller power. Moreover, peak shaving would bring a reduction of CO2 emissions due to decrease of electrical power generated by fossil fuels fired thermal power plants that are currently covering peak loads [4]. The content in this paper provide the review on work going on in development of LHTES over the world.

II PHASE CHANGE MATERIALS (PCM)

Thermal energy can be stored in PCMs as a heat of vaporization (liquid‑vapour transition) or heat of fusion (solid‑liquid transition) and later can be used.

2.1 Classification of PCM

The Fig. 1 below shows the entire family of PCMs.
PCMs are mainly classified as organic and inorganic depending upon the thermal, chemical and physical properties they are classified. Depending upon the range of melting points and properties a selection procedure is followed to select PCM for a particular application [1]. The main goal of this paper is to provide a comprehensive review on previous studies concerning its application for thermal management of buildings.

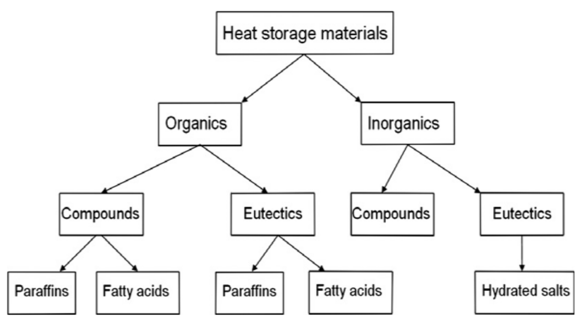

Fig.1 Classification of PCM

Materials to be used for phase change thermal energy storage must have a large latent heat and high thermal conductivity. They should have melting or freezing temperature in the practical range of application. The hydrated salts, paraffin waxes, fatty acids and eutectics of organic and non-organic compounds are widely used as phase change materials since last 30 years [5].

III REVIEW OF RESEARCH TRENDS

The number of articles concerning the integration of PCMs in buildings to improve their energy efficiency has been increasing during the last decade. Before 2003 there were only few articles were published on this topic but after

2003 a lot of research and published papers shows the growing interest of application of PCM for increasing building energy efficiency. In 1983 A. Abhat published on types and properties of PCMs and their application in thermal energy storage systems [6]. Table 1 gives the relative reviews on the latent heat storage with PCMs up to present day. Most reviews deal with the general problem of TES using PCMs, focusing on the PCMs characterization/classification and on the building active and passive applications. However, during the last years more specific issues were reviewed and its foreseeable that the article reviews concerning the problem of integrating PCMs in buildings, to meet the demand for thermal comfort and energy conservation/savings purpose.

IV SOME PHYSICAL AND THEORETICAL CONSIDERATIONS

4.1 Building as a Thermodynamic System

The building is a quite complex thermodynamic system, submitted to internal and external solicitations, and a passive ideal energy conservation building is difficult to attain. Considering the building as thermodynamic system continuous approach of the researchers has been focused on improvement of building materials.L. Karim et. al[7] proposes the improvement of the energy performance of hollow concrete floor panel through the insertion of a phase change material (PCM) in enclosures of the floor panel in order to significantly increase the thermal inertia of the wall. In a sustainable approach, buildings should be designed to ensure thermal comfort of occupants during the whole year, with a minimum auxiliary energy for heating and cooling.

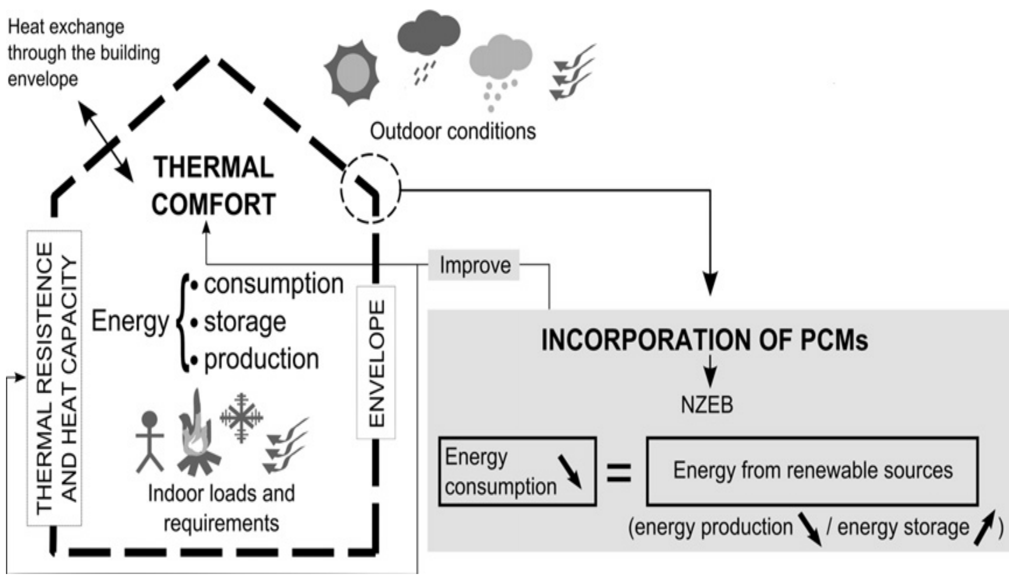

Fig2. Building as a thermodynamic system

In Fig. 2 the building is sketched as a thermodynamic system. The buildings envelope is the boundary of the system and the balance between the energy production within the building (or nearby), the energy consumption and the energy storage during the operational phase of the building is shown. By this picture the scope for thermal energy storage can be predicted and recent developments in practical aspects can be studied [8].

4.2 Lightweight and heavyweight building Envelopes.

Lightweight buildings such as steel or wood frame show certain advantages over heavyweight buildings, such as masonry and concrete. Labet et. al. has Experimentally assessed PCM to air heat exchanger storage system for building ventilation application and found it works better for lightweight buildings[9]. A model and a corresponding numerical procedure, based on the finite-difference method, have been developed for lightweight and heavyweight buildings for the prediction of buildings thermal behavior under the influence of all possible thermal loads and the ‘‘guidance’’ of cooling control system in conjunction with thermal comfort requirements [10]. Regarding thermal comfort, the main disadvantage of lightweight construction is their low thermal mass and low thermal inertia [11]. In short, the behavior of buildings with high or low thermal inertia is different, and the integration of PCMs in these buildings should reflect those behaviors.

V INCORPORATION OF PCMS INTO BUILDING ELEMENTS

Once the PCMs have been selected, based primarily on the temperature range of application and on their thermo physical properties, it is important to evaluate how they could be incorporated within passive LHTES systems (construction materials or building elements). The first method is the simplest and most economical one. The liquid or powdered PCM is directly mixed with construction materials such as plaster and applied on the outer envelope of building [12]. Lee et. al. has assessed the effects of applying thin PCM layer on building wall and found the peak heat flux reductions were 51.3% and 29.7% for the south wall and west wall, respectively [13].Now a days PV panels can also be coupled with the LTES give best results. The performance of an industrial building using a thermal storage tank coupled with heat pumps was studied for the summer cooling period by Artconi et. al. by means of dynamic simulations. Implementing TES with PV panels is quite expensive needs much capital cost and hence greater payback period [14] Table 1. Below shows the research trend over the years.

Table 1. The increase in the research on PCM for buildings over the years

Ref.	Journal	Year	Content
[39]	*Solar Energy*	1983	Low temperature latent heat thermal energy storage: heat storage materials
[44]	*Building and Environment*	2001	A low energy building in a life cycle−its embodied energy
[23]	*Heat and Mass Transfer*	2004	Thermal regulation of building-integrated photovoltaic using phase change materials
[24]	*Heat and Mass Transfer*	2005	Numerical investigation of a PCM-based heat sink with internal fins
[2]	*Building and Environment*	2007	Application of latent heat thermal energy storage in buildings: State-of-the-art
[20]	*Applied Thermal Engineering*	2008	Experimental investigation thermal performance of a building roof incorporating PCM for thermal mngt
[34]	*Energy and Buildings*	2009	The impact of auxiliary energy on the efficiency of the heating and cooling system: Monitoring of low-energy buildings
[10]	*Energy and Buildings*	2011	Numerical simulation of cooling energy consumption in connection with thermostat operation

			mode and comfort requirements for the Athens buildings
[11]	*Energy and Buildings*	2012	PCM based thermal management system for cool energy storage application in building: An experimental study
[29]	*Applied Energy*	2012	Thermal enhancement of plastering mortars with Phase Change Materials: Experimental and numerical approach
[1]	*Applied Energy*	2012	Review on phase change materials (PCMs) for cold thermal energy storage applications
[3]	*Energy and Buildings*	2012	Review of PCM based cooling technologies for buildings
[5]	*Energy and Buildings*	2013	Review of passive PCM latent heat thermal energy storage systems towards building energy efficiency,
[27]	*Applied Energy*	2013	Thermal energy storage strategies for effective closed greenhouse design,
[6]	*Energy and Buildings*	2013	Development of phase change materials for building applications
[16]	*Energy and Building*	2014	Optimization of PCM embedded in a floor panel developed for thermal management of the lightweight envelope of buildings
[21]	*Applied Thermal*	2014,	Thermal performance of building element containing phase change material (PCM) integrated with ventilation system An experimental study
[31]	*Renewable Energy*	2014,	Modeling phase change materials behavior in building applications: Comments on material characterization and model validation,
[36]	*Thermal Engineering*	2014	Brick masonry walls with PCM macrocapsules: An experimental approach,
[7]	Energy and Buildings	2015	New phase-change material components for thermal management of the light weight envelope of buildings
[9]	Applied Thermal	2015	Experimental assessment of a PCM to air heat exchanger storage system for building ventilation application
[12]	Applied Energy	2015	Energy refurbishment of existing buildings through the use of phase change materials
[15]	Energy and Buildings	2015	Thermal performance of an aluminum honeycomb wall board incorporating microencapsulated PCM
[13]	*Applied Energy,*	2015	Assessing the integration of a thin phase change material (PCM) layer in a residential building wall for heat transfer reduction and management
[37]	*Thermal Engineering*	2015	The use of lightweight aggregate saturated with PCM as a temperature stabilizing material for road surfaces
[4]	*Energy and Buildings*	2016	Thermal performance assessment of encapsulated PCM based thermal management system to reduce peak energy demand in buildings
[17]	*Energy and Buildings*	2016	Experimental evaluation of the heat transfer through small PCM-based thermal energy storage units for building applications
[19]	Renewable Energy	2016	Thermal energy storage in building integrated thermal systems: A review.
[18]	*Energy and Buildings*	2016	Thermal performance investigation and optimization of buildings with integrated phase change materials and solar photovoltaic thermal collectors
[14]	*Renewable Energy*	2016	Thermal energy storage in building integrated thermal systems: A review
[22]	*Thermal Engineering*	2016	A comparative study on PCM and ice thermal energy storage tank for
[25]	*Applied Energy*	2016	air-conditioning systems in office buildings
[26]	*Building and Environment*	2016	CFD analysis of melting process in a shell-and-tube latent heat storage for concentrated solar power plants,
[28]	*Applied Energy*	2016	Investigation on the properties of a new type of concrete blocks incorporated with PEG/SiO2 composite phase change material
[32]	*Energy and Buildings*	2016	Energy performance of double shape-stabilized phase change materials wallboards in office building,
[35]	Building Materials	2016	Influence of phase change material on mechanical and thermal properties of clay geopolymer mortar

5.1 PCM Enhanced Wallboards

Wallboards are very suitable for the incorporation of PCMs. They are cheap and widely used in building applications, especially in lightweight construction the use of microencapsulated PCM into honeycomb structure for wallboards has increased energy efficiency [15].

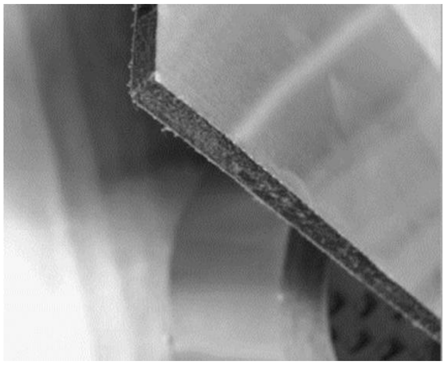

Fig3. 60% PCM encapsulated wallboards [16]

Royon et. al. [17] presented a parametric study carried out to evaluate the charging and discharging phases of microencapsulated PCMs the results obtained can be used in the design and optimization of new TES systems for buildings. It has been found that when PCM wallboards integrated with solar photovoltaic thermal (PVT) collectors work very efficiently [18]. Navarro et. al.[19] has presented a benchmarking review on Thermal energy storage in building integrated thermal systems.

5.2 PCM in Walls

Athanasius et. al.[20]has Experimental investigated the thermal performance of a building walls incorporating phase change material (PCM) for thermal management. It is found that ambient temperature for room with PCM walls maintained lower comparatively to the room with only concrete walls.

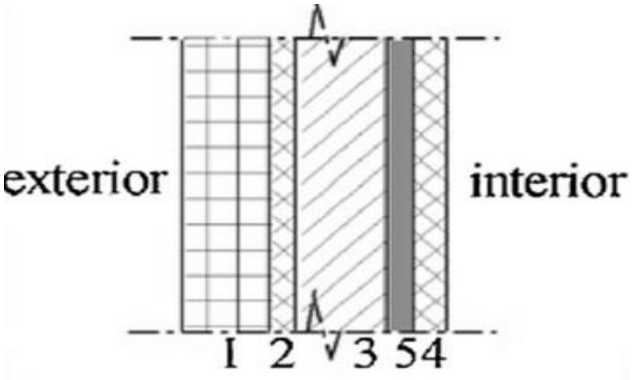

Fig4. Wall with PCM [22]

It has been found that Ice based thermal energy storage tank can effectively reduce the load on office air conditioning system [22]. The research has showed that the laminated PCM sample with a Photovoltaic cell shows large energy efficiency.

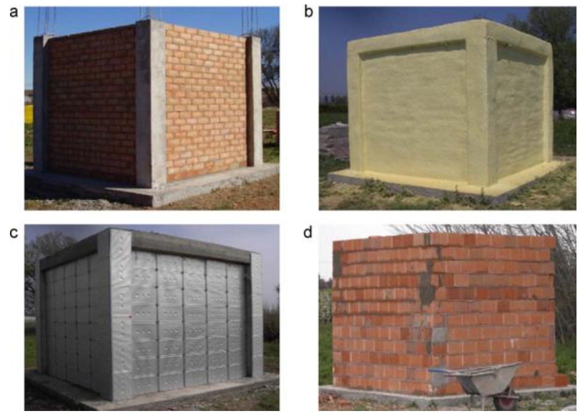

Fig5. (a),(b),(c),(d) shows the walls incorporated with PCM from outside

5.3 PCM bricks

The objective of the PCM brick system is to reduce the heat flow from outdoor space by absorbing the heat gain in the brick before it reaches the indoor space during the daytime. At night, the stored heat is released to indoor and outdoor spaces. The effects of different design parameters such as the PCM's quantity, type, and location in the brick was investigated and the results showed that, for the best configuration, the heat flux at the indoor space can be reduced by 17.55%.[29]

Fig6. Bricks with holes for PCM

Azhena et. al. [29] has studied the effect of incorporating PCM into plaster mortar and bricks and has found a new composition for a construction material with enthalpy of 25 kJ/kg in a melting range from 23 ◦C to 25 ◦C; and thermal conductivity of 0.3 W/m◦C. The new material saving 25% PCM.

5.4 PCM Shutters, Window Blinds and Translucent PCM walls

Exterior PCM shutters containing PCMs are movable structural shading elements associated to windows fac¸ ades. The PCM shutters system must operate cyclically, reflecting the ongoing daily cycles of 24 h. Similarly, the cyclically operation of the system should enable the fusion of the PCM mass during the day and its solidification during the night, enabling the daily cyclic storage and release of thermal energy. The PCM-shutter system is to be opened during the day to maximize the solar direct gains indoors through the glass window and, simultaneously, to allow its charging. During the night, the system must be closed to minimize the heat losses through the window and to allow its discharging by releasing the thermal energy indoors.

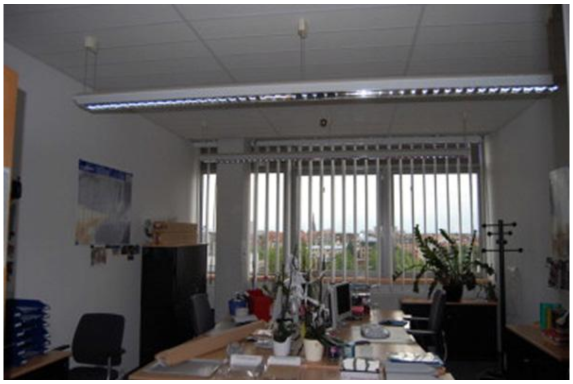

Fig7. Office with PCM shutters, window Blinds,

VI FUTURE OUTLOOK

In the works available in the literature, most of the systems are Numericaly studied/optimized for extreme winter or summer conditions Further work should be done in order to integrate the construction solutions with PCMs in the buildings' thermal regulation codes worldwide, e.g. some methodologies must be developed to take into account the latent heat loads from the PCMs' phase change processes in the buildings' project, mainly for the cases where the dynamic simulation of the energy throughout the year is not mandatory. Emerging economies in high need of housing, and the thermal refurbishment of existing buildings in the developed countries are great opportunities for the development of new construction solutions with PCMs. Further work should be done to convert new types of PCMs, new methods to incorporate them into building materials and new heat transfer enhanced techniques in the design of passive LHTES systems.

VII CONCLUSION

This paper provides a comprehensive review on previous studies related to the evaluation of how, and where, PCMs are used in passive LHTES systems, and how these construction solutions are related to building's energy efficiency. It was concluded that PCM passive LHTES systems can contribute to (i) increase indoor thermal comfort (ii) improve buildings envelope performance and to increase thermal efficiency (iii) decrease the conditioning power needed by reduction of the heating and cooling peak loads (iv)reduce energy consumption;(v) take advantage of renewable sources like solar thermal energy; (vi) save money during the operational phase; and (vii) contribute for the reduction of CO2 emissions associated to heating and cooling.

REFERENCES

[1] E. Oro, A. Gracia, A. Castell, Review on phase change materials (PCMs) for cold thermal energy storage applications, International Journal of Applied Energy , 99, 2012, 513-533.

[2] Y. Zhang, G. Zhou, K. Lin, Application of latent heat thermal energy storage in buildings: State-of-the-art and outlook, International Journal of Building and Environment,42 ,2007, 2197-2209.

[3] E. Ostermana, V. Tyagib, V. Butalaa, Review of PCM based cooling technologies for buildings, International Journal of Energy and Buildings, 49, 2012, 37–49.

[4] V. Tyagi, A. Pandey, D. Buddhi, Thermal performance assessment of encapsulated PCM based thermal management system to reduce peak energy demand in buildings, International Journal of Energy and Buildings, 117,2016, 44–52.

[5]N. Soares, J. Costab, A. Gasparb, Review of passive PCM latent heat thermal energy storage systems towards building energy efficiency, International Journal of Energy and Buildings,59,2013, 82-103.

[6] A. Sharma, A. Shukla, C. Chen, Development of phase change materials for building applications, International Journal of Energy and Buildings ,64, 2013, 403-407.

[7] L. Karim, F. Barbeon, P. Gegout, New phase-change material components for thermal management of the light weight envelope of buildings, International Journal of Energy and Buildings,68,2014, 703-706.

[8] H. Zhang, J. Baeyens, G. Caceres, Thermal energy storage: Recent developments and practical aspects, International Journal of Progress in Energy and Combustion Science, 53, 2016, 1-40.

[9] M. Labat, J. Virgone, D. David, F. Kuznik, Experimental assessment of a PCM to air heat exchanger storage system for building ventilation application, International Journal of Applied Thermal Engineering, 66, 2014, 375-382.

[10] C. Tzivanidis, K. Antonopoulos, F. Gioti, Numerical simulation of cooling energy consumption in connection with thermostat operation mode and comfort requirements for the Athens buildings, International Journal of Applied Energy, 88, 2011, 2871-2884.

[11] V. Tyagi, D. Buddhi, R. Kothari, PCM based thermal management system for cool energy storage application in building: An experimental study, International Journal of Energy and Buildings, 51, 2012, 248-254.

[12] F. Ascione, N. Bianco, R. Masi, Energy refurbishment of existing buildings through the use of phase change materials: Energy savings and indoor comfort in the cooling season, International Journal of Applied Energy, 113, 2014, 990-1007.

[13] K. Lee, M. Medina, E. Raith, Assessing the integration of a thin phase change material (PCM) layer in a residential building wall for heat transfer reduction and management, International Journal of Applied Energy,137,2015, 699-706.

[14] A. Arteconi, E. Ciarrocchi, Q. Pan, Thermal energy storage coupled with PV panels for demand side management of industrial building cooling loads, International Journal of Applied Energy,123,2016, 456-460.

[15] C. Lai, S. Hokoi, Thermal performance of an aluminum honeycomb wall board incorporating microencapsulated PCM, International Journal of Energy and Buildings,73, 2014, 37-47.

[16] L. Royon, L. Karima, A. Bontemps, Optimization of PCM embedded in a floor panel developed for thermal management of the lightweight envelope of buildings, International Journal of Energy and Building,82, 2014, 385-390.

[17] N. Soares, A. Gaspar, P. Santos, Experimental evaluation of the heat transfer through small PCM-based thermal energy storage units forbuilding applications, International Journal of Energy and Buildings,116 ,2016,18–34.

[18] W. Lin, Z. Ma, P. Cooper, Thermal performance investigation and optimization of buildings with integrated phase change materials and solar photovoltaicthermal collectors, International Journal ofEnergy and Buildings, 116, 2016, 562–573.

[19] L. Navarro, A. Gracia, S. Colclough, Thermal energy storage in building integrated thermal systems: A review. Part 1.active storage systems, International Journal of Renewable Energy, 88, 2016, 526-547.

[20] A. Pasupathy, L. Athanasius, R. Velraj, Experimental investigation and numerical simulation analysis onthe thermal performance of a building roof incorporating phase change material (PCM) for thermal management, International Journal of Applied Thermal Engineering,28, 2008,556‑565.

[21] M. Jaworski, Thermal performance of building element containing phase change material (PCM) integrated with ventilation system An experimental study, International Journal of Applied Thermal Engineering,78,2014, 665-674.

[22] M. Rahdar, A. Emamzadeh, A. Ataei, A comparative study on PCM and ice thermal energy storage tank forair-conditioning systems in office buildings, International Journal of Applied Thermal Engineering ,96, 2016, 391-399.

[23] M. Huang, P. Eames, B. Norton, Thermal regulation of building-integrated photovoltaics using phase change materials, International Journal of Heat and Mass Transfer, 47, 2004,2715-2733.

[24]V. Shatikian, G. Ziskind , R. Letan, Numerical investigation of a PCM-based heat sink with internal fins, International Journal of Heat and Mass Transfer,48, 2005, 3689-3706.

[25] F. Fornarelli, S.M. Camporeal, M. Torresi, CFD analysis of melting process in a shell-and-tube latent heat storage for concentrated solar power plants, International Journal ofApplied Energy,164, 2016, 711–722.

[26] T. Xu, Q. Chen, Z. Zhang,Investigation on the properties of a new type of concrete blocks incorporated with PEG/SiO2 composite phase change material, International Journal of Building and Environment,104, 2016, 172-177.

[27] A. Vadiee, V. Martin, Thermal energy storage strategies for effective closed greenhouse design, International Journal of Applied Energy, 109, 2013, 337–343.

[28] X. Mi, R. Liu, H. Cui, Energy and economic analysis of building integrated with PCM in different cities of China, International Journal of Applied Energy,175, 2016, 324–336.

[29] A. Sa, M. Azenhab, H. Sousaa, Thermal enhancement of plastering mortars with Phase Change Materials: Experimental and numerical approach, International Journal of Energy and Buildings, 49, 2012, 16–27.

[30] K Lee, M. Medina, Using phase change materials for residential air conditioning peak demand reduction and energy conservation in coastal and transitional climates in the State of California, International Journal of Energy and Buildings, 116, 2016, 69–77.

[31] Y. Dutil, D. Rousse, S. Lassue, Modeling phase change materials behavior in building applications: Comments on material characterization and model validation, International Journal of Renewable Energy, 61, 2014, 132-135.

[32] N. Zhu, P. Liu, F, Liu, Energy performance of double shape-stabilized phase change materials wallboards in office building, International Journal of Applied Thermal Engineering, 105, 2016, 180–188.

[33] M. Huang, P. Eames, B. Norton, Thermal regulation of building-integrated photovoltaics using phase change materials, International Journal of Heat and Mass Transfer, 47, 2004, 2715–2733.

[34] D. Kalz, S. Herkel, A.Wagner, The impact of auxiliary energy on the efficiency of the heating and cooling system: Monitoring of low-energy buildings, International Journal of Energy and Buildings ,41, 2009, 1019–1030.

[35] Z. Wanga, H. Su, S. Zhao, Influence of phase change material on mechanical and thermal properties of clay geopolymer mortar, International Journal ofConstruction and Building Materials,120,2016, 329–334.

[36] R. Vicente, T. Silva, Brick masonry walls with PCM macrocapsules: An experimental approach, International Journal of Applied Thermal Engineering, 67, 2014, 24-34.

[37] M. Ryms, W. Lewandowski, E. Radziemska, The use of lightweight aggregate saturated with PCM as a temperature stabilizing material for road surfaces, International Journal ofApplied Thermal Engineering,81, 2015, 313-324.

[38]N. Zhu, P. Liu, F. Liu,Energy performance of double shape-stabilized phase change materialswallboards in office building, , International Journal ofApplied Thermal Engineering,105, 2016, 180–188.

[39] A. Abhat, Low temperature latent heat thermal energy storage: heat storage materials, , International Journal of Solar Energy 30, 1983, 313-332.

[40] O. Kofoworola, S. Gheewala, Environmental life cycle assessment of a commercial office building in Thailand, International Journal of Life Cycle Assessment 13,2008, 498‐511.

[41] B. Rosselló-Batle, A. Moià, A. Cladera, Energy use, CO2 emissions and waste throughout the life cycle of a sample of hotels in the Balearic Islands, International Journal of Energy and Buildings, 42, 2010, 547‐558.

[42] N. Mithraratne, B. Vale, Life cycle analysis model for New Zealand houses, International Journal of Building and Environment, 39, 2004, 483‐492.

[43] Y. Chang, R.J. Ries, Y. Wang, The embodied energy and environmental emissions of construction projects in China: an economic input‐output LCA model, International Journal of Energy Policy, 38,2010, 6597‐6603.

[44] C. Thormark, A low energy building in a life cycle–its embodied energy,energy need for operation and recycling potential, International Journal of Building and Environment, 37, 2001, 429‐435.

[45] T. Ramesh, R. Prakash, K.K. Shukla, Life cycle energy analysis of buildings: an overview, International Journal of Energy and Buildings, 42,2010,1592‐1600.