Jasna Radulović[1)]
Danijela Nikolić[1)]
Jasmina Skerlić[1)]
Mina Vasković[1)]

1) Faculty of Mechanical Engineering, University of Kragujevac, Serbia
{jasna@kg.ac.rs, danijelan@kg.ac.rs, jskerlic@gmail.com, mina.vaskovic@gmail.com}

USE OF PHASE CHANGE MATERIALS FOR BUILDING INTEGRATION

Abstract: *Solar energy has a very important influence on the environment. The development of new technologies in this area is very important for numerous reasons and is topic of many studies today. Integration of phase change materials (PCMs) into building structures has been found as appropriate for application in Building integrated systems. These materials have applications in buildings for effective use of solar energy. There is large number of PCMs that melt and solidify at wide range of temperatures, making them attractive in a number of applications, but many more applications are yet to be discovered. This paper investigates the possibility of using PCMs for building integration of Building Integrated Systems.*
Keywords: *Phase change materials, Building integrated systems*

1. INTRODUCTION

In the building sector there is a new tendency to integrate solar thermal technologies into buildings. These systems are known as Building-Integrated Solar Thermal (BIST) [1]. BIST systems also cover other types of BI solar configurations such as Photovoltaic (PV) and Photovoltaic/Thermal (PVT).

The solar collectors used for standard BISTSs are of various designs and built using different types of material. Plastic plates or black painted metal (usually copper based on high corrosion resistance and rarely steel or aluminium) are most often used as absorbers on solar collectors. For the purposes of solar collector glazing, low-iron glass is the most utilized material. The insulation material used for flat plate solar collectors' insulation is a selective grade of CFC free polyurethane foam (PUF).

Furthermore, BIPV systems are based on different technologies. Silicon (Si) is the most commonly used material here. Due to its high efficiency, silicon is the leading material when PV cells technology is concerned. The first generation corresponds to the most commercially available crystalline silicon PVs. The second generation corresponds to thin film technology PVs. Rather than a crystal structure; the structure of silicon atoms of amorphous silicon cells is a thin homogenous layer. Amorphous silicon cells are composed of silicon atoms in a thin homogenous layer rather than a crystal structure. After silicon, the new technologies were developed, based on compounds of cadmium sulphide, cadmium telluride, cuprous sulphide, gallium arsenide, copper indium gallium selenide/copper indium selenide and dye-sensitized solar [2]. The third generation consists of still in research phase PVs with mainly concentrated PVs, quantum dots PVs and hybrid PVs [3].

The fast paced technology development during the last decades of XX century led to the appearance of several new materials suitable for use in BISTS, such as phase change materials (PCMs), nanomaterials and nanofluids, which revealed many interesting properties reported in the past decades [4]. The unique set of features of these materials offers unprecedented potential for various applications, including Building Integrated Solar Thermal Systems. Innovative ideas such as systems with phase change materials are very promising in future prospect.

This paper is organized in the following way: in Section 2 classification of PCMs from aspect of their application for building integration is given, PCM application in BISTS is presented in Section 3, and final remarks are given in Section 4.

2. CLASSIFICATION OF PCMs

A large number of PCMs are available in any required temperature range. PCMs utilize the latent heat of phase change to control temperatures within a specific range.

Matherial changes the state from solid to liquid with the temperature increase by apsorbing the heat in endothermic process. The opposite reaction happens when the temperature decreases. As the phase change temperature, obtained from energy used to alter the phase of material, is around comfort room temperature, indoor climate becomes more comfortable and stable in buildings with phase change materials. This will also cut peak cooling and heating loads. Good performance of used PCMs can be accomplished in buildings with low thermal mass, increasing the heat storage capacity, where temperature range depends on PCMs used [5].

PCMs may be generally classified as organic, inorganic and eutectics. These categories are further divided based on the various components of the PCMs and one of classifications is given in Fig. 1 [6].

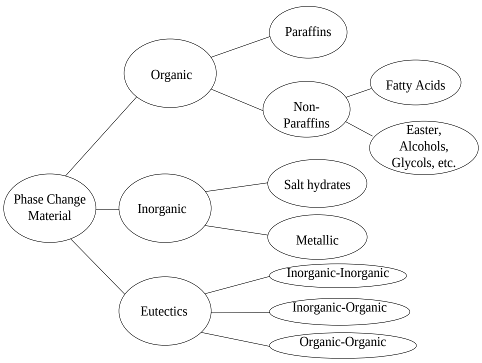

Figure. 1 – General categorization of PCMs

Another classification, Fig. 2, where difference in melting enthalpy and melting temperature for some of the most common materials used as PCMs was suggested by Cabeza et al. in [7].

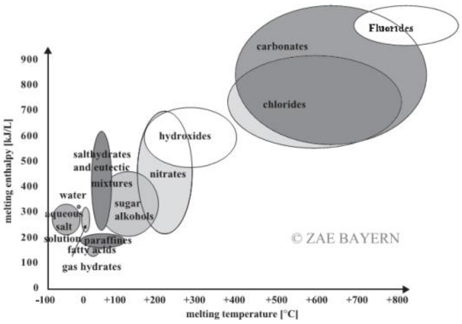

Figure 2 – Classes of materials that can be used as PCM with regard to their typical range of melting temperature and melting enthalpy (graph: ZAE Bayern) [7]

2.1 Organic PCMs

Organic PCMs are divided into paraffin and non-paraffin. Organic materials include congruent melting, self nucleation and usually non-corrosiveness to the container material [6].

Paraffins are available in a large temperature range (Fig. 2) opening up for use in various other areas besides building related applications. Non-paraffins used as PCMs include fatty acids and their fatty acid esters and alcohols, glycols, etc. Fatty acids have received the most attention for use as PCMs in buildings. The most interesting fatty acids for PCMs purposes include lauric acid, myristic acid, palmiticacid and stearic acid. Organic PCMs have many qualities which make them suited for building applications. However, the fact that many organic PCMs are considered flammable is a crucial drawback for which impacts the safety aspect of organic PCMs considerably when aimed at building applications [4, 5].

2.2 Inorganic PCMs

Inorganic materials are further classified as salt hydrate and metallic. These phase change materials do not supercool appreciably and their heats of fusion do not degrade with cycling [6]. Inorganic compounds have a high latent heat per unit mass and volumes are low in cost in comparison to organic compounds and are non-flammable.

For building applications however, metallic are not within the desired temperature range and in addition they have severe weight penalties making them unsuited. Hydrated salts consist of an alloy of inorganic salts and water and enable a cost-effective PCM due to easy availability and low cost. The phase change transformation involves hydration or dehydration of the salts in a process that resembles typical melting and freezing. The salt hydrate may either melt to a salt hydrate containing less water or to an anhydrous form where salt and water is completely separated [4, 6].

2.3 Eutestic mixtures

A eutectic is a minimum-melting composition of two or more components, each of which melts and freeze congruently, forming a mixture of the component crystals during crystallization [8]. Eutectics can be made as organic–organic, inorganic–inorganic or organic–inorganic mixtures. This gives space for a wide variety of combinations that can be appropriate for specific applications.

The most commonly studied organic eutectic mixtures consist of fatty acids. Capability to obtain more desired properties such as a specific melting point or a higher heat storage capacity per unit volume is one of advantages of eutectic mixtures. The thermo-physical properties are to be tested and proved in the future, which makes them adequate for further investigations, as well for applications in building sector [4].

3. PCM APPLICATIONS IN BISTS

The incorporation of PCM in different applications in BISTS has grown interest to the researcher.

PCM can be used in thermal energy storage applications. Investigation and analysis of the available thermal energy storage systems incorporating PCM for use in different applications are summarizes by
Sharma et al. in [6].

The ideal PCM to be used for any thermal storage system must meet following requirements: high sensitive heat capacity and heat of fusion; stable composition; high density and heat conductivity; chemical inert; non-toxic and non-inflammable; reasonable and inexpensive. In the nature, the salt hydrates, paraffin and paraffin waxes, fatty acids and some other compounds have high latent heat of fusion in the temperature range from 30ºC to 80ºC that is interesting for solar applications. PCM's are chemical substances that undergo a solid-liquid transition at temperatures within the desired range for heating purposes. During the transition process, the material absorbs energy as it goes from a solid to a liquid and releases energy as it goes back to a solid. Most organic PCMs are non-corrosive and chemically stable; they exhibit little or no subcooling, and are compatible with most building materials and have a high latent heat per unit weight and low vapor pressure [4].

The integrated PCM solar collector storage concept is economically promising in low temperature solar water heating systems for domestic, agricultural and industrial applications. A system of this type combines collection and storage of thermal energy into a single unit. This integrated solar collector storage water heater approach was developed from early systems and comprised simply of a simple black vessel placed in the solar collector. Integrated PCM solar collector for a low-temperature SDHW system using salt hydrate eutectic mixture where the PCM is held inside the collector and thermally discharged to cold water flowing through a heat exchanger is developed by [9]. Integrated system is shown in Fig. 3.

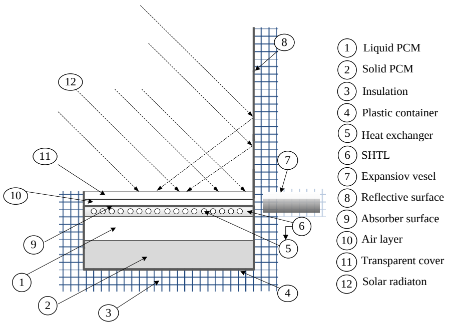

Figure.3 – Integrated PCM solar collector storage system designed

A type of water-PCM solar collector consisting of two adjoining sections is developed in [10]. One section is filled with water and the other with paraffin wax, where melting temperature is in range 45–50º C, as it is shown Fig. 4. The experimental results indicated that the water temperature could exceed 55º C during a typical day of high solar radiation and remain over 30º C during the whole night.

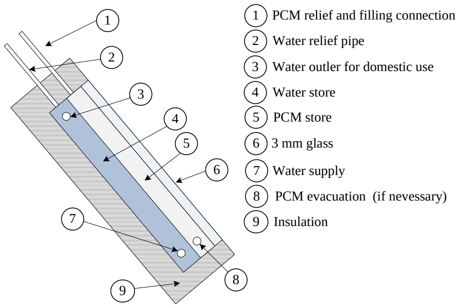

Figure 4 – Schematic view of solar collector construction with PCM

The key component in the solar domestic hot water system using phase change materials is the latent heat storage unit. Many researchers focused on improving the heat transfer inside it, in order to improve the energy storage and thermal performance of solar hot water systems. Two main fields of interest are configuration of the latent heat storage unit to improve heat transfer inside the unit, and the heat transfer mechanism in the PCM [11].

A large number of solid–liquid PCMs have been investigated for heating and cooling applications [6].

One interesting application of PCMs, which combined phase change materials in a roof-integrated BIPV/T air system is given below. A ceiling ventilation PV/T system improved by phase change materials (PCMs) was developed by Lin et al. in [12]. This system is called PVT–PCM integrated ventilation system, Fig. 5.

This system was compared to two different designs: PCM without a PV/T collector and a ceiling without any system attached.

Two experiments were conducted, in winter and summer climate conditions. The outlet air temperature of the PCM-PV/T system was maintained in range of approximately 20.6º -24.5º C in winter climate conditions. Without PV/T collector the outlet air temperature was below the melting point of PCM (21º C) in same conditions. Thus the PCM acts as an insulator when there is no PV/T collector attached to it. Also, unlike the other two designs which coused temperature fluctuations between day-time and night-time, the proposed systems were able to maintain the indoor temperature at 18.9 º C.

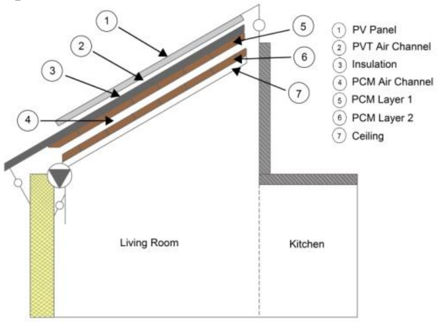

Figure 5 – PVT–PCM integrated ventilation system

In summer climate conditions the proposed PCM system and PCM without PV/T collector system gave similar values. This is due to weak radiative cooling effect of the PV/T system. During the summer, PCM-PV/T and ceiling-PV/T systems had the average thermal and electrical efficiencies of 13.6% and 8.26% respectively. Enhancement of the thermal performance during winter was achieved by adding PCM onto PV/T system [13].

Apart from providing solar heating during winter day time, electricity generation and sky radiative cooling during night time, this system also increases insulation plus thermal energy storage with the PCM component [14].

4. CONCLUSION

PCMs have received considerable attention over the last decade as very attractive materials in a number of applications. They represent an innovative solution that can contribute to the improvement of the energy performance of buildings. Incorporation of phase change materials into building structures has been found as useful for reduction of temperature fluctuations, while main-taining the thermal comfort.

This study demonstrated that the use of PCMs can play an essential role in solar thermal applications. PCMs have predictable applications in buildings for effective use of solar energy, but many more applications are yet to be discovered.

REFERENCES:

[1] Lamnatou, Chr., Mondol, J.D., Chemisana, D., Maurer, C., "Modelling and simulation of Building-Integrated solar thermal systems: Behaviour of the coupled building/system configuration", *Renewable and Sustainable Energy Reviews* (2015), 48:178–191

[2] Kalogirou S., "Solar thermal collectors and applications", *Progress in Energy and Combustion Science,* (2004), 30:231–295

[3] Kim J. et al, "Review of life cycle assessment of nanomaterials in photovoltaics", *Solar Energy* (2016) 133:249–258

[4] Radulovic, J., Nikolic, D., Blagojevic, M., Miletic, I., Vaskovic, M., "*A review of new materials used for building integrated systems*", First International Conference on Building Integrated Renewable Energy Systems, Dublin Institute of Technology (DIT) Ireland, 6th - 9 th March 2017.

[5] Kalnæs, S.E., Jelle B.P., "Phase change materials and products for building applications: A state-of-the-art review and future research opportunities". *Energy and Buildings*, (2015), 94:150–176

[6] Sharma, A., Tyagi, V.V., Chen, C.R., Buddhi, D., "Review on thermal energy storage with phase change materials and applications" *Renewable and Sustainable Energy Reviews,* (2009), 13:318–45.

[7] Cabeza, L.F., Castell, A., Barreneche, C., Gracia, A., Fernández, A.I., "Materials used as PCM in thermal energy storage in buildings: a review", *Renewable and Sustainable Energy Reviews*, (2011), 15:1675–1695.

[8] Tyagi, V.V., Buddhi D., "PCM thermal storage in buildings: a state of art" *Renewable and Sustainable Energy Reviews,* (2007), 11:1146–66.

[9] Rabin, Y., Bar-Niv, I., Korin, E., Mikic, B., "Integrated solar collector storage system based on a salt-hydrate phase-change material" *Solar Energy* (1995), 55:435–44.

[10] Kürklü, A., Özmerzi, A., Bilgin, S., "Thermal performance of a water-phase change material solar collector", *Renewable Energy,* (2002),26:391–9.

[11] Seddegh, S., Wang, a X., Henderson, A. D., Xing, Z., "Solar domestic hot water systems using latent heat energy storage medium: A review", *Renewable and Sustainable Energy Reviews* (2015), 49:517–533

[12] Lin, W., Zhenjun Ma, Z., Sohel, M.I., Cooper, P., "Development and evaluation of a ceiling ventilation system enhanced by solar photovoltaic thermal collectors and phase change materials", *Energy Conversion and Management* (2014), 88:218–230

[13] Baljit, S.S.S., Chan, Hoy-Yen., Sopian, K., "Review of building integrated applications of photovoltaic and solar thermal systems", *Journal of Cleaner Production* (2016) 137:677-689

[14] Yang, T, Andreas, K., Athienitis., "A review of research and developments of building-integrated photovoltaic/thermal (BIPV/T) systems", *Renewable and Sustainable Energy Reviews* (2016) 66:886–912

Acknowledgment: This paper is a result of two projects: TR33015 supported by the Ministry of Science and Technological Development of Republic of Serbia, and COST action TU1205-BISTS supported by EU. The authors thank to the all institutions for their financial support.