RESEARCH PAPER

The Behavior of Glauber's Salt as a Heat Storage Material for Residential Iraqi Buildings

Marwa Hamid Wasmi¹, Hayder Mohammed Jaffal², Tawfeeq Wasmi Mohammed³

¹ Department of Materials Eng., Mustansiriyah University, Iraq
² Department of Mechanical Eng., Mustansiriyah University, Iraq
³ Department of Materials Eng., Mustansiriyah University, Iraq

A B S T R A C T:
Phase change materials (PCMs) are regarded as a possible solution for reducing the energy consumption required for space heating by storing heat during daytime and releasing it at night. Glauber’s salt (Na₂H₄(SO₄)₂·12H₂O) is one of the inorganic phase change materials. It possesses some desired properties over other PCMs such as low melting point, high thermal capacity and high thermal conductivity. The present study assists in evaluation of Glauber’s salt as a PCM for heating required in residential buildings. The PCM was integrating with a glazed roof of a rig model to absorb the heat comes from sun during daytime and releasing it to the inside at night. Building considerations and thermo-physical properties of PCMs have been taken into account, while the ambient conditions and indoor conditions have measured experimentally. Results obtained showed that the indoor temperature could increase by 2-4 °C in the winter compared to that measured in a traditional one. Furthermore, a simulation program depended on degree-days method explained that the energy consumption could be saved up to 10%.

KEY WORDS: Glauber's salt; PCMs; Heating; Energy saving; Solar energy.

1. INTRODUCTION:

The climate of Iraq as an arid region encourages researchers to seek the benefit of high potential of solar energy, where many sites receive effective solar radiation up to 2,300 kWh/m² yearly (Abdulsada et al 2015), and about 5 kWh/m² daily in winter as an average (Doyle et al 2010). Thus, heat storage in building elements could be a solution to reduce energy consumption especially at winter nights. Phase change materials (PCMs) store the heat (as sensible and latent) in daytime and releases it nightly. It is found that PCMs could absorb about 86% of the exposed heat flux during daytime (Rouhollah et al 2015).

Many methods have been investigated for the utilization of PCM in the buildings, such as wallboards containing PCMs (Alvarode et al 2015; Murat et al 2016; Murat et al 2017; Chengqiang et al 2017). PCMs could be filled into sandwich wall, concrete walls, concrete block and concrete floors (Yusuf 2016; Subbiah 2017; Chenglong et al 2017; Lidia et al 2014; Ahmad et al 2016; Jianli et al 2009; Entrop et al 2011; Xing et al 2011; Hyun et al 2017; Esam 2008). PCMs also implied as insulation permeating into the building and furniture (Xiangfei et al 2013; Xu et al 2016; Karunesh et al 2017; Lu et al 2017; Hicham et al 2016). It is clear that the majority of studies (about 80 %) have focused on the applications of PCMs in the walls as a development of encapsulation technology (Kuznik et al 2011), but several promising investigations...
have taken place in the field of using PCMs integrating with the roof of the buildings (Karthik 2010; Mushtaq et al 2013; Stéphane et al 2015; Ayca et al 2015; Dong et al 2015; Hagar et al 2017; Mushtaq et al 2018). However, the recent study focuses on the integration of PCM in the roof of the building because the roof is the main source of thermal loss in the building envelope.

During the past decade, many researchers have investigated salt hydrates as heat storage materials. Inorganic PCMs like salt hydrates have some attractive properties including: high latent heat value, higher thermal conductivity, low melting point and low cost in comparison to organic compounds like paraffin wax. On the other hand, they have some disadvantages including: corrosiveness, chemical instability, and may suffer from super-cooling effects, phase segregation and incongruent melting due to non-homogenous composition (Letcher 2016; Mehling et al 2008; Mettawee et al 2007). However, (Ryu et al 1992) have submitted a technique to eliminate phase segregation of inorganic hydrated salt PCMs by potential of thickening agents. A common compound, such as sodium sulfate decahydrate (Na2SO4·10H2O), is thickened with a suitable absorbent polymer (as effective thickener) to prevent phase segregation. The experiments showed that most hydrate salts could be stabilized by adding 3-5 wt % of the thickener.

A suggestion by (Hadjieva et al 2000) described a procedure to impregnate porous concrete by the salt hydrate PCMs as a method of reducing the effects of phase segregation in inorganic PCMs. Their hypothesis predicted that the absorption of sodium thiosulphate pentahydrate (hydrated salt PCM) into a porous concrete containing cavity and a large unfolded surface would avoid a precipitation of incongruent melting of the PCM. The experiment involved impregnating cylindrical samples of porous concrete with the hydrated salt PCM, and then measuring the thermo-physical properties of the new composite before, during, and after thermal cycling. The results from the experiment found that the concrete’s large absorption areas served as a good supporting matrix for the PCM and improved its thermal cycling. Even though salt hydrates have some problems related to supercooling effects and phase segregation but several studies still focusing on the advantages of these PCMs in energy conservation. Furthermore, a sufficient overview of getting benefit of salt hydrates in many storage systems is given by (Hale et al 1971; Brunberg 1980; Duane et al 1981; Belen et al 2003; Milan 2010; Zondag et al 2013; Schmidt et al 2014; Jong et al 2014; Michel et al 2016; Gaeini et al 2016; Donkers et al 2017; Ashley et al 2017).

2. EXPERIMENTAL WORK

The aim of this study is to design and operate a heating system depending on the using of salt hydrates as phase change materials (PCMs) by integrating with the roof of the building. The reason of integrating PCM with the roof is due to the most exposed to sun, hence maximum efficiency of the system. The evaluation of the performance could be satisfied depending of the thermal analysis. The PCM used was inorganic material (Glauber's salt) with the thermo-physical properties mentioned by (Belen et al 2003; USF 2018) and listed in Tab.1. This material has been collected locally and filled into 20 bags. The dimensions of each PCM bag were 12 cm x 10 cm with 4-5 mm thickness.

The work has been done experimentally using a rig model built for that purpose in Baghdad (33o.3, 44o.4) at Mustansiriyah University, Materials Engineering Department. The model is located at the terrace floor with dimensions of 1m x 1m x 1m, as shown in Fig.1. The walls and the floor are constructed from 1 cm common MDF (medium density fiber) with 4 cm internal insulation by EPS (Expanded polystyrene). The insulated walls and floor have a U-value of 1.35 W/m2 K and covered with Alufoils to reflect the radiation inside and assure well mixing of indoor air. The roof is totally exposed to sun and covered by 5 mm clear glass. There is a hole of 9 cm2 in the north façade (rear side) in order to satisfy infiltration by 0.4 ACH in average, which is necessary to avoid condensation as well as to offer fresh air. The scheme of the system is shown in figure 2. The PCMs bags have arranged together in a net under the glass by 10 cm away, as shown in Fig 3. There is a slot in the space between the glass and the PCMs layer in order to put an insulated glass-fiber, from sunset time till sunrise time, to avoid heat loss to the outside. The mechanism of (glazed roof, PCMs layer and
insertable fiber in between) satisfies integrated and effective system with maximum heat storage as well as less heat losses. The experimental readings have been obtained during the sunny days of January 2018, where heating is in a peak demand in the winter of Iraq (mostly at night). The study served several instruments like: thermometer data logger (Lutron-947SD) with temperature sensors (Type-K). The sensors have set to measure the temperatures of: PCMs, indoor air, outdoor air and glass each 30 minutes during the entire day. Solar power meter (Lutron-1116SD) was used to measure the incident solar radiation horizontally each hour.

3. RESULTS AND DISCUSSIONS

The study includes in-site measurements in a model built for the purpose of reducing the heating demand using the Glauber's salt as a PCM. In January, the ambient temperature almost swings between 6 °C at night to 20 °C daytime on clear days with daytime duration of 10 hours and maximum solar radiation up to 675 W/m². In order to evaluate the performance of PCM in heat storage, the PCM layer was installed in many days and removed in other days. Samples of readings are selected in the analysis of this study. For the case of with-PCM, Fig 4, 5 and 6 show the variation of outdoor, indoor, PCM and glass temperatures for the entire days of 28, 29 and 30 Jan 2018, respectively. The outdoor temperatures were swinging from 5 °C (at 7:00 AM) to 18 °C (at 2:00 PM) with solar radiation up to 650 W/m². The average indoor temperature with PCM was 25 °C with maximum value of 39 °C at 2:00 PM and minimum value of 9 °C at 7:00 AM. The indoor temperature at the night was decreasing from 20-9 °C with an average of 15 °C. Furthermore, the PCM temperature was swinging between 7-40 °C. The effect of super-cooling is well cleared at night where the PCM temperature, and indoor temperature as a sequence, fall down rapidly. This problem is very common in inorganic PCM materials and could be treated by adding a thickener (usually polymer) as mentioned earlier. For the case of without-PCM, Fig 7, 8 and 9 show the variation of outdoor, indoor and glass temperatures for the entire days of 27, 31 Jan and 1 Feb 2018, respectively. The outdoor temperatures were swinging from 6 °C (at 7:00 AM) to 19 °C (at 2:00 PM) with solar radiation up to 675 W/m². The average indoor temperature without PCM was 22 °C with maximum value of 35 °C at 2:00 PM and minimum value of 9 oC at 7:00 AM. The indoor temperature at the night was decreasing from 18-8 oC with an average of 12 oC.

The results of comparison between two cases clarified that there is increasing of the indoor temperature due to the using of PCM by 2-4 oC most of the time. Also, the results have showed that the PCMs can maintain indoor temperature above 20 oC for 10 hours daily, while for the case of without-PCM it was only for 8 hours daily, thus delay the peak time for 2 hours at early night.

Based on the current results it could estimate the heating load for the sample days to show the energy saving thus the performance of PCM. A simulation program depended on degree-days method is established according to (Marwa et al. 2019) and the results of calculation are shown in Tab. 1. The °F for base temperature °C in Tab. results explained that the energy consumption for the model with PCM was 318 kJ/m² daily as an average. On the other hand, the energy consumption for the model without PCM was 582 kJ/m² daily as an average. So, it could say that the using of Glauber's salt saved the energy by 45% even that salt hydrates have some problems related to super-cooling effects and phase segregation.

4. CONCLUSION:

Phase change materials (PCMs) applied with a glazed roof is an approach to reduce heating load of the building and increase thermal comfort by improving its thermal storage capacity. The recent study submits Glauber's salt as an effective PCM, where the performance is evaluated depending of the thermal analysis of experimental data. Results have shown that these materials have a good potential to reduce heating demand hours at °F and delay the peak time for early night. The indoor temperature for the model with PCM has an average value of 15 oC at night hence an increasing by 2-4 oC comparing to that measured for the model without PCM. Furthermore, a simulation program depended on degree-days method explained that the energy consumption for the model with PCM has an average value of 318 kJ/m², hence a reduction of
45% comparing to that calculated for the model without PCM. Hence, the using of Glauber's salt as a PCM has advantages in terms of high heat capacity and thermal conductivity even that it has some problems related to super-cooling effects, phase segregation and incongruent melting.

**Acknowledgements:** Authors are grateful to all support given by College of Engineering, Mustansiriyah University, where the present work was extracted from a master project done in the university.

### Table 1. Thermo-physical properties of PCM used in the study.

| Name of PCM                | Glauber's Salt – Na₂SO₄.10H₂O (Inorganic) |
|----------------------------|---------------------------------------------|
| Density                    | 1485 kg/m³                                  |
| Melting point              | 32 °C                                       |
| Specific heat of solid     | 1760 J/kg.K                                 |
| Specific heat of liquid    | 3320 J/kg.K                                 |
| Heat of fusion             | 254 kJ/kg                                   |
| Thermal conductivity      | 0.6 W/m.K                                   |
| Total weight               | 1.6 kg                                      |

### Table 2. Heating load for selected days.

| Date   | Load with PCM (kJ/m²) | Load without PCM (kJ/m²) |
|--------|------------------------|--------------------------|
| 27 Jan | -                      | 570                      |
| 28 Jan | 316                    | -                        |
| 29 Jan | 295                    | -                        |
| 30 Jan | 343                    | -                        |
| 31 Jan | -                      | 596                      |
| 1 Feb  | -                      | 581                      |
| Avg.   | 318                    | 582                      |

Energy saving = \( \frac{\text{Load without PCM} - \text{Load with PCM}}{\text{Load without PCM}} \times 100 \% = 45\% \)
Figure 4. Readings on 28 Jan 2018 (Max Rad=650 W/m²).

Figure 5. Readings on 29 Jan 2018 (Max Rad=675 W/m²).

Figure 6. Readings on 30 Jan 2018 (Max Rad=600 W/m²).

Figure 7. Readings on 27 Jan 2018 (Max Rad=600 W/m²).

Figure 8. Readings on 31 Jan 2018 (Max Rad=675 W/m²).

Figure 9. Readings on 01 Feb 2018 (Max Rad=675 W/m²).
References

Abdulsada G, Tawfeeq W (2015), Experimental and theoretical study for the performance of new local thermal insulation in Iraqi building, Renewable Energy in the Service of Mankind, Vol I, pp. 487-501, Springer.

Ahmad H, Khaled A, Hamza A, Yasir R and Shaimaa A (2016), Effect of phase change materials (PCMs) integrated into a concrete block on heat gain prevention in a hot climate, Sustainability, Vol. 8, pp. 1-14.

Alvarode G and Luisa F (2015), Phase change materials and thermal energy storage for buildings, Energy and Buildings, Vol. 103, pp. 414-419.

Ashley B, Martin K, Thomas S and Evangelos I (2017), PCMs for residential building applications: a short review focused on disadvantages and proposals for future development, Buildings, 7, 78, MDPI.

Ayca T, Tahsin B and Cengiz S (2015), An experimental and numerical investigation on the use of phase change materials in building elements: The case of a flat roof in Istanbul, Energy and Buildings 102, pp. 91–104.

Belen Z, Jose M, Luisa F and Harald M (2003), Review on thermal energy storage with phase change: materials, heat transfer analysis and applications, Applied Thermal Engineering, 23, pp. 251–283.

Brunberg E (1980), The Tepidus system for seasonal heat storage and for cooling, Proc int sem on thermo-chem energy storage, pp. 247-260.

Chenglong L, Lijie X, Jie J, Mengyin L and Dan S (2017), Experimental study of a modified solar phase change material storage wall system, Energy, Vol. 128, pp. 224-231.

Chengqiang Y, Pengfei J, Yun L, Chengying Q and Xian R, (2017), Development and thermal performance of an expanded perlite-based phase change material wallboard for passive cooling in building, Energy and Buildings, Vol. 152, pp. 547-557.

Donkers P, Sögütoglu L, Huinink H, Fischer H and Adan O (2017), A review of salt hydrates for seasonal heat storage in domestic applications, Applied Energy, 199, pp. 45-68.

Dong L, Zheng Y, Liu C and Guozhong W (2015), Numerical analysis on thermal performance of roof contained PCM of a single residential building, Energy Conversion and Management, 100, pp. 147–156.

Doyle P and Khalidah J (2010), Iraq has an opportunity to become a solar leader, Developments, DAI newsletter, pp. 9-11, Spring Issue, www.dai.com

Duane G and Kim H (1981), Design considerations in the use of Glauber salt for energy storage, Report for Utah Water Research Laboratory, USA.

Entrop A, Brouwers H and Reinders A (2011), Experimental research on the use of micro-encapsulated phase change materials to store solar energy in concrete floors and to save energy in Dutch houses, Solar Energy, Vol. 85, pp. 1007-1029.

Esam M (2008), Thermal analysis of a building brick containing phase change material, Energy and Buildings, Vol. 40, pp. 531-557.

Gaeini M, Zondag H and Rindt C (2016), Effect of kinetics on the thermal performance of a sorption heat storage reactor, Appl Therm Eng, 102, pp. 520-531.

Hagar E, Stefano F, Valentina S, Roberto Z and Ernesto B (2017), Experimental and numerical analyses on thermal performance of different typologies of PCMs integrated in the roof space, Energy and Building, 150, pp. 546-557.

Hicham J and Heiselberg P (2016), Influence of internal thermal mass on the indoor thermal dynamics and integration of phase change materials in furniture for building energy storage: A review, Renewable and Sustainable Energy Reviews, Vol. 69, pp. 19-32.

Hyun B, Masayuki M, Youngjin C and Takeshi K (2017), Experimental analysis of thermal performance in buildings with shape stabilized phase change materials, Energy and Buildings, Vol. 152, pp. 524-533.

Hadjieva M, Stoykov R and Filipova T (2000), Composite salt-hydrate concrete system for building energy storage, Renew. Energy, 19, pp. 111–115.

Hale D, Hoover M., O’Neill M (1971), Phase change materials handbook, Lockheed Missiles and Space Co., Research and Engineering Center, USA.
Jianli L, Ping X, Hong H, Wenyi D and Jinmin H (2009), Preparation and application effects of a novel form-stable phase change material as the thermal storage layer of an electric floor heating system, Energy and Buildings, Vol. 41, pp. 871-880.

Jong J, Trausel F, Finck C, Van L and Cuypers R (2014), Thermochemical heat storage-system design issues, Energy Procedia, 48, pp. 309-319.

Karthik M (2010), Application of phase change material in buildings: field data vs. EnergyPlus simulation, Master thesis submitted to Arizona State University.

Karunesh K, Shukla A and Sharma A (2017), Heat transfer studies of building brick containing phase change materials, Solar Energy, Vol. 155, pp. 1233-1242.

Kuznik F, David D, Johannes K and Roux J (2011), A review on phase change materials integrated in building walls, Renewable and Sustainable Energy Reviews, Elsevier, 15 (1), pp. 379-391.

Letcher T (2016), Storing energy: with special reference to renewable energy sources, Elsevier, Oxford.

Lidia N, Alvaro G, Albert C, Servando A and Luisa F (2014), Design of a prefabricated concrete slab with PCM inside the hollows, Energy Procedia, Vol. 57, pp. 2324-2332.

Lu L, Hang Y and Rui L (2017), Research on composite-phase change materials (PCMs) bricks in the west 1 wall of room-scale cubicule: mid-season and summer day cases, Building and Environment, Vol. 123, pp. 494-503.

Marwa H, Hayder M and Tawfeeq W (2019), Integrating roof with phase change materials for heating purpose as an application of energy saving, MSc Thesis, Mustangiriyah University, College of Engineering.

Mehling H and Cabeza L (2008), Heat and cold storage with PCM: an up to date introduction into basics and applications, Springer, Germany.

Mettawee E and Assassa G (2007), Thermal conductivity enhancement in a latent heat storage system, Sol. Energy, 81, pp. 839–845.

Michel B, Mazet N and Neveu P (2016), Experimental investigation of an open thermochemical process operating with a hydrate salt for thermal storage of solar energy: local reactive bed evolution, Appl Energy, 180, pp. 234-244.

Milan O (2010), Phase change materials for improved thermal indoor comfort, Brno University of Technology. Available online on:

https://www.donau-uni.ac.at/imperia/md/content/department/bauenumwelt/news/4_ostry.pdf

Murat K and Khamid M (2016), Passive thermal control in residential buildings using phase change materials, Renewable and Sustainable Energy Reviews, Vol. 103, pp. 371-398.

Murat K and Khamid M (2017), Experimental study on thermal performance of phase change material passive and active combined using for building application in winter, Applied Energy, Vol. 206, pp. 293-302.

Mushtaq T, Ahmed Q and Hasanain M (2013), Experimental and numerical study of thermal performance of a building roof including phase change material (PCM) for thermal management, Global Advanced Research Journal of Engineering, Technology and Innovation, Vol. 2(8), pp. 231-242.

Mushtaq I, Hadi O and Ahmed O (2018), Experimental investigation of phase change materials for insulation of residential buildings, Sustainable Cities and Society, 36, 42–58.

Rouhollah A and Amir S (2015), Energy saving in building using PCM on windows, Proceedings of 14th conference of international building performance simulation association, India, Dec. pp. 7-9.

Ryu H, Woo S, Shin B and Kim S (1992), Prevention of subcooling and stabilization of inorganic salt hydrates as latent heat storage materials, Sol. Energy Mate: Sol. Cells, 27, pp. 161–172.

Schmidt M, Szczukowski C, Roßkopf C, Linder M and Wörner A (2014), Experimental results of a 10 kW high temperature thermochemical storage reactor based on calcium hydroxide, Appl Therm Eng, 62 (2), pp. 553-559.

Stéphane G, Frédéric M, Dimitri B, Bruno M and Harry B (2015), Experimental investigation on a complex roof incorporating phase change material, Energy and Buildings, Elsevier, 108, pp.36-43.

Subbiah M (2017), Analysis of solar heat gains and environmental impact of the phase change material.
(PCM) wall, Innovative Energy & Research, Vol. 6, pp. 1-6.

USF (2018), Phase-change media for CSP thermal energy storage, Notes from University of South Florida. Available on http://philipmyers.myweb.usf.edu/toppage2.htm, accessed on 12 Jan 2018.

Xiangfei K, Shilei L, Jingyu H, Zhe C and Shasha W (2013), Experimental research on the use of phase change materials in perforated brick rooms for cooling storage, Energy and Buildings, Vol. 62, pp. 597-604.

Xing J and Xiaosong Z (2011), Thermal analysis of a double layer phase change material floor, Applied Thermal Engineering, Vol. 31, pp. 1576-1581.

Xu W, Hang Y, Lu L and Mei Z (2016), "Experimental assessment on the use of phase change materials (PCMs) bricks in the exterior wall of a full-scale room, Energy Conversion and Management, Vol. 120, pp. 81-89.

Yusuf A (2016), Diurnal performance analysis of phase change material walls, Applied Thermal Engineering, Vol. 102, pp. 1-8.

Zondag H, Kikkert B, Smeding S, Boer D and Bakker M (2013), Prototype thermochemical heat storage with open reactor system", Appl Energy, 109, pp.360-365.