Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 161 (2019) 352–359

Energy Procedia

www.elsevier.com/locate/procedia

2nd International Conference on Sustainable Energy and Resource Use in Food Chains, ICSEF 2018, 17-19 October 2019, Paphos, Cyprus

Experimental study on the performance of a new encapsulation panel for PCM's to be used in the PCM-Air heat exchanger

Thiago Santos[a,b,*], Maria Kolokotroni[a], Nick Hopper[c], Kevin Yearley[c]

[a]*Brunel University London, Institute of Energy Futures, RCUK Centre for Sustainable Energy use in Food chains (CSEF), Uxbridge, UB8 3PH, United Kingdom*
[b]*Federal Institute of Pernambuco, Av. Prof Luiz Freire, 500, Recife/PE –Brazil*
[c]*Monodraught Ltd. Halifax house, Halifax Road, High Wycombe, United Kingdom*

Abstract

The experimental work evaluated the thermal performance of a new panel design to encapsulate Phase Change Material (PCM) and compare this with an existing panel commercially available and incorporated within a PCM-Air heat exchanger system. The analysis was focused on the melting and solidifying time of the PCM within each panel design. It also focused on the thermal load of the 'Latent Thermal Energy Storage' (LTES) of a thermal battery module, each battery module consisting of multiple panels stacked together with an air gap between each panel. The existing battery modules consisted of 9 panels while the new module has 7 panels, with all panel filled with an industry recognised PCM. The new design battery module is now able to hold 17.5 kg more PCM than the existing one, resulting in 30% more material than the existing module. The air temperature used for melting and solidifying was 30°C and 15°C respectively, with a constant airflow of 75 l/s. Tests were carried out first with one battery module and then with an additional battery module in series and compared with a three-layer-calorimeter test (3LC). The results of the new design battery indicated an increase in time to melt and solidify the PCM due to the additional material within each battery module.

Selection and peer-review under responsibility of the 2nd International Conference on Sustainable Energy and Resource Use in Food Chains, ICSEF2018

Keywords: Thermal energy storage; Phase change material; Thermal performance; PCM-Air heat exchanger;

---

[*] Corresponding author. Tel.: +55 81 97221574
E-mail address: thiagosantos@ipojuca.ifpe.edu.br

Selection and peer-review under responsibility of the 2nd International Conference on Sustainable Energy and Resource Use in Food Chains, ICSEF2018.
10.1016/j.egypro.2019.02.105

1. Introduction

PCM-Air heat exchangers are one of many Thermal Storage Systems (TES) application under constant study and development [1–4]. The TES consists of a phase change material thermal storage usually integrated into a mechanical ventilation system; to be referred to as MVS in this study. The equipment uses the principle of thermal storage to store latent heat in climates where the nights are cold enough to charge (or solidify) the PCM and use it to cool the environment during the day. In MVS, the Latent Thermal Energy Storage (LTES) is the key of the equipment, which makes the selection of the appropriate PCM and the encapsulation vital to reach the best performance. Recent reviews [2–4] point out that a critical component in the PCM-Air heat exchanger is the design of an encapsulation panel and in particular, the heat transfer channels. One solution is to increase the PCM material but this will result in larger space requirements or develop a material with higher conductivity but this will increase the final cost of the MVS. Another solution is to increase the heat transfer rate of the existing encapsulation panel as PCM materials have a lower thermal conductivity. Santos et al. [5] proposed an optimised design based on heat transfer, pressure drop, cost of production and ease of manufacturing based on CFD analysis backed by experimental validation. The optimised design was fabricated and the present paper intends to evaluate the thermal performance of the PCM-air heat exchanger unit with the new design battery module and compare it with the existing module. The experimental study comprises of the charging and discharging test and the thermal load test.

2. Experimental setup

The experimental rig consists of a duct with components used from a commercial MVS. The airflow was measured with an airflow meter (Sensing Precision Balance Master 4250, [6]) and a ventilation system with water heater was used to provide stable inlet temperatures. The airflow of 75 l/s was used because it is the maximum airflow used by the MVS during its operational charging period. Datataker DT 80 with the extension CEM20 was used to log inlet, surface, and outlet temperatures. To ensure that the PCM was fully charged or discharged, 12 thermocouples were attached on the panel surface (six on the top and six on the bottom) located at the middle of the thermal battery. For the first thermal battery, three thermocouples were also attached to the bottom and upper panel to analyse if the thermal battery is charging and discharging uniformly. The results of the first test for both new and existing battery module confirmed the uniformity in temperature. Due to that, the second thermal battery module have thermocouples attached only on the middle panel. Fig. 1 shows the test rig with all components used and the configuration of 1 and 2 thermal batteries used for both existing and new panel test. Fig. 2 presents the test rig mounted.

2.1. Experimental procedure

To estimate cooling and heating load and melting/solidifying time of the existing and new thermal battery, thermocouples were attached on panels' surface with a logging interval of 15 seconds. The thermal battery (TB) was considered fully charged or discharged when temperatures were stable and close to the set point (30 °C for discharging and 15 °C for charging). The cooling source was the outside air and the charging period takes place from 00:00 (midnight) until 12:00 (noon). The discharging period was from 12:00 (noon) until 00:00 (midnight).

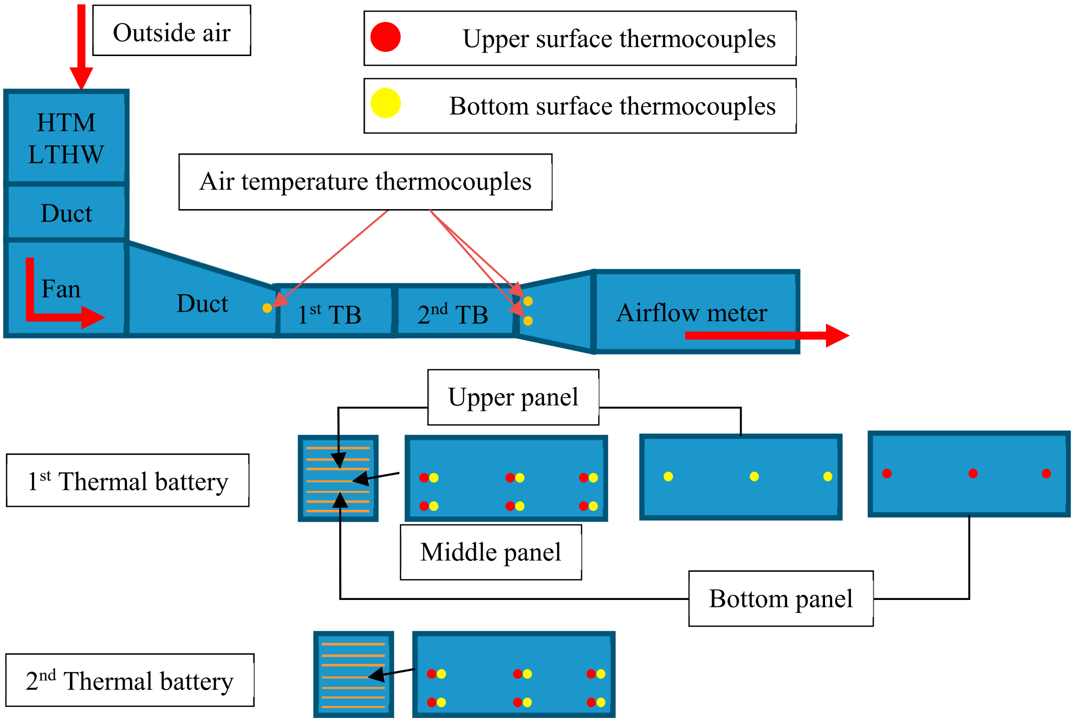

Fig. 1. Test configuration of 1, 2 and 3 thermal batteries for both existing and new panel (HTM/LTHW: Hybrid Thermal Mixing/Low Temperature Hot Water)

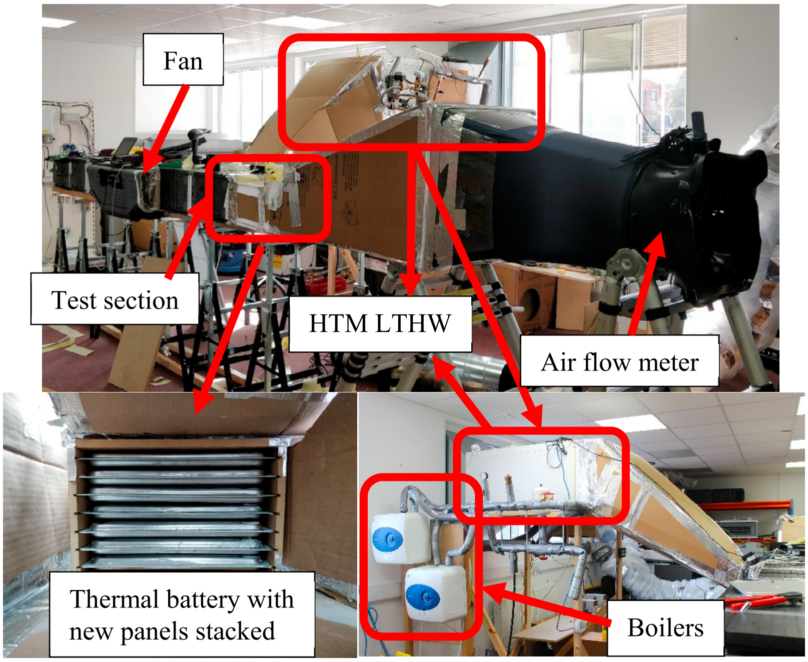

Fig. 2. Test rig for melting and solidifying tests

To analyse the cooling/heating load of the phase change, a control volume was applied for the air (Fig. 3), thus:

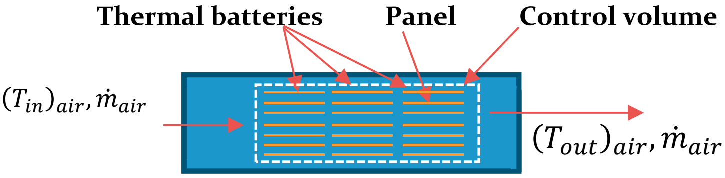

Fig. 3. Control volume for cooling/heating load for 1 and 2 thermal batteries

$$\boldsymbol{Q_c = \int_0^t \dot{m}_{air}\, c_{p,air}\, (T_{out} - T_{in})_{air}\, dt} \tag{1}$$

$$\boldsymbol{Q_h = \int_0^t \dot{m}_{air}\, c_{p,air}\, (T_{out} - T_{in})_{air}\, dt} \tag{2}$$

Where Q_c is the cooling load provided by the thermal battery during the melting period (12:00 – 24:00) and Q_h is the heating load during the solidifying period (00:00 – 12:00). T_{in} and T_{out} is the inlet and outlet temperature for each time step dt (15 seconds); $\dot{m}_{air}$ is the airflow measured by the airflow meter (in kg/s) and $c_{p,air}$ the heat capacity of the air. The air properties used were the same as the one applied during the design process (300 K) by Santos et al [5]. For this test, thermal losses were neglected. This procedure is in agreement with several studies in this field [7–12].

3. Results and discussion

3.1. Charging and discharging time

Fig. 4a presents the results for one thermal battery. It can be seen that more time is needed to charge and discharge the new TB, this is due to the capability of the new TB to hold 17.5 kg (total latent heat of 3202.5 kJ) against 13.5 kg (total latent heat of 2470.5 kJ) of the existing TB. This 30 % extra PCM made the surface temperature of the new TB solidify and melt gradually while the phase change in the existing TB (which has a thinner panel) is more pronounced. Due to that, Fig. 4a clearly shows the onset and endset for both melting and solidifying (20-18 ºC and 24-26 ºC, respectively) for the existing TB. When two thermal batteries are used (Fig. 4b), a similar behaviour was found.

In terms of time required to melt and solidify, the TB is considered fully charged or discharged when the surface temperature achieve stability. From Fig. 4, it is clear that the new TB needs more time to complete the cycle and this is explained by the capacity that the new TB can hold. However, the time required to solidify is lower than the time to melt due to the PCM properties. This is an interesting result as the MVS needs less time to charge the TB. For one TB, 4h is necessary to solidify the existing TB while 5h30min is needed for the new TB, an increase of 38 %. For two TB, 8h30min is needed to charge the new TB and while 5h is needed for the existing TB, representing 66 % more time.

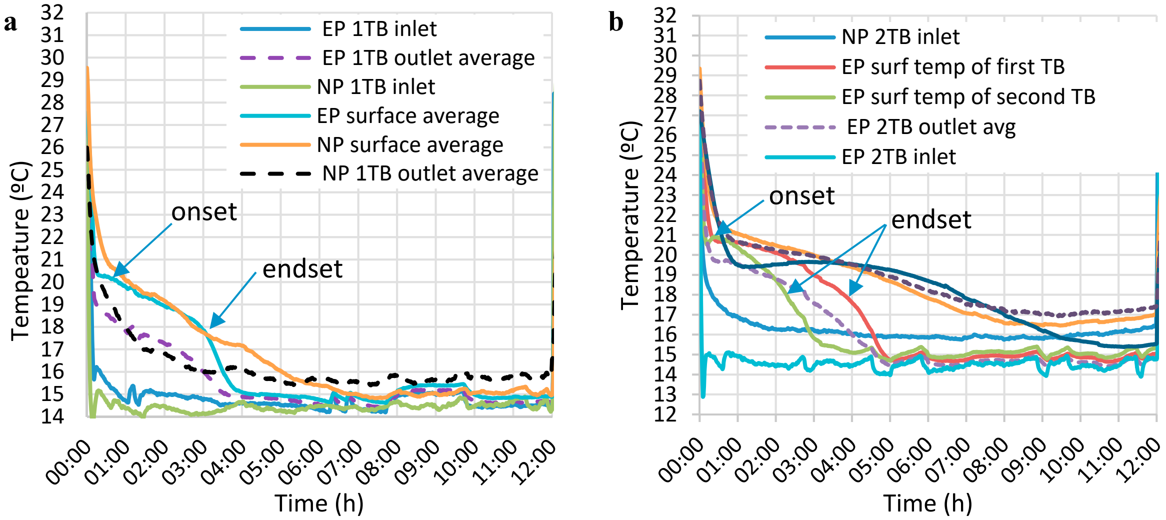

Fig. 4. Solidifying temperature for the existing (a) and new panel (b) with one and two thermal batteries.

When the discharging period is analysed, the new TB is capable of providing cooling for a longer period of time. This is explained by the additional PCM it can hold. As it can be seen in Fig. 5a, the outlet temperature gradually increases to reach the inlet temperature. For 1 TB with the existing panel, the TB is completely discharged after 3h30min while the new TB need approximately 6h30min to completely discharge, an increase of 86 %. When a MVS with 2 TB is analysed (Fig. 5b), the existing TB is fully discharged after 4h30 min while the new TB needs the double of the time.

This can be confirmed by Table 1 which summarizes the time required and the increase in percentage from new to existing thermal battery.

Table 1. Melting and solidifying times for one and two thermal batteries

			Time (h)	Increase (in %)
1TB	Melting	EP 1TB	3.5	86 %
		NP 1TB	6.5	
	Solidifying	EP 1TB	4.0	38 %
		NP 1TB	5.5	
2TB	Melting	EP 2TB	4.5	100 %
		NP 2TB	9.0	
	Solidifying	EP 2TB	5.0	70 %
		NP 2TB	8.5	

Santos et al. [5] indicated that the new panel is capable to double the heat transfer when compared to the existing one. This is an important feature when a faster thermal response is needed. However, Fig. 5 shows that the temperature for the existing and new TB increase at the same rate until the PCM starts to melt. This could be explained by number of panels the existing TB have. With two panels more when compared to the new TB, it has 28 % more surface area and this reflects in an outlet temperature similar to the new TB. For the same reason, the outlet temperature during the solidifying period in Fig. 4 shows a similar pattern.

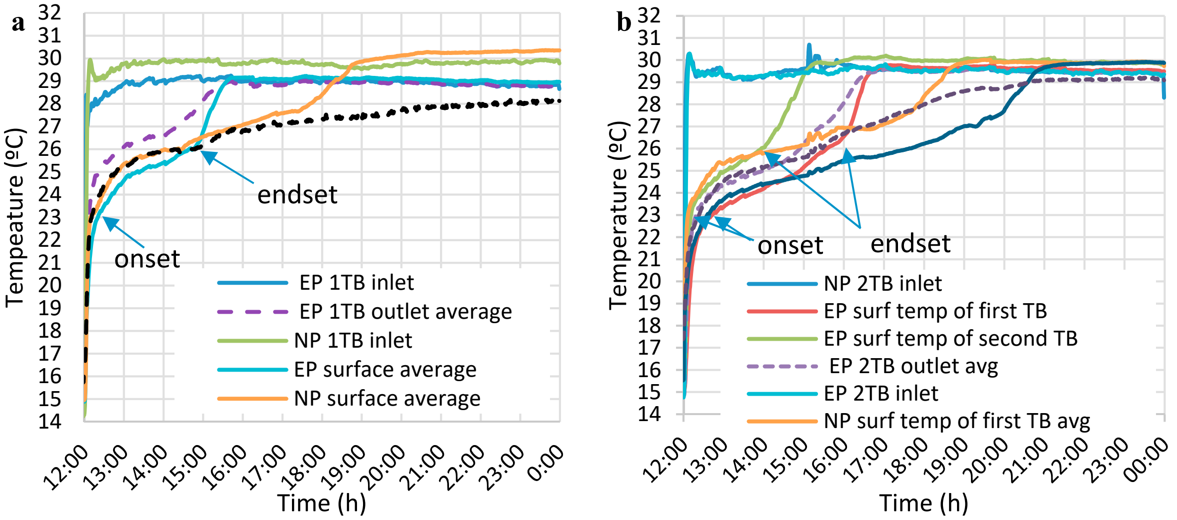

Fig. 5. Melting temperature for existing and new panel with (a) one and (b) two thermal batteries.

3.2. Thermal load

During the melting and solidifying process, the air was cooled down or heated up to a correspondent cooling (Q_c) or heating load (Q_h). To estimate those values, equations 1 and 2 were used. The heating and cooling cycle ceased when outlet temperature stabilises and achieve values close to the inlet temperature. These results are presented in Fig. 6a and Fig. 6b. Interestingly, the melting test of new thermal battery with one module provides a faster response when compared to the existing thermal battery and the opposite occurs for two TB. This is probably caused by fluctuations in temperature during the transition from charge to discharge mode and vice-versa.

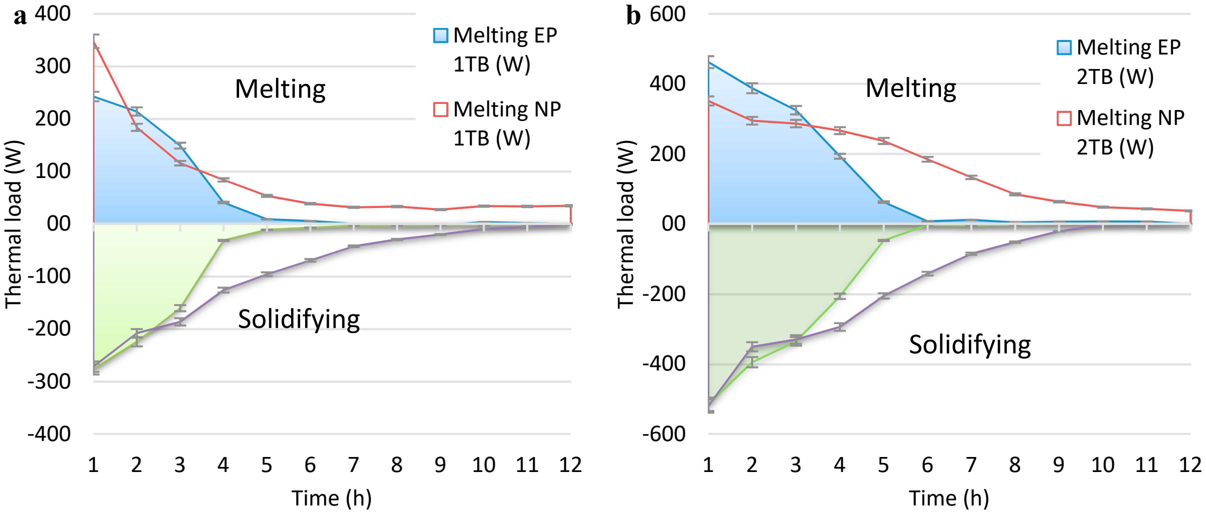

Fig. 6. Thermal load for existing and new panel with one (a) and two (b) thermal batteries with error bar showing the uncertainty of 3.7 %.

From Fig. 6a, it can be seen that after 4h for 1 TB, the TB is fully melted or solidified as a small amount of energy is released or absorbed by the TB. For the new TB, 6h30min is needed to complete the cycle and after this time, the energy released or absorbed by the TB remains stable. A similar pattern occurs with 2 TB (Fig. 6b) where more time for solidification was needed. This is explained by 8kg of extra PCM that the two TB are holding, which also results in more energy stored.

To validate the melting and solidifying test, the results were compared with a 3LC (three-layer calorimetry) test provided by the manufacturer. The results for both the heat up and cooling are presented in Table 2.

Table 2. Typical properties of the PCM used in the experimental study

	Typical value (3LC)	**Units**
Peak melting temperature	24	ºC
Total stored heat, 15°C to 30°C (melting)	218	kJ/kg
Peak crystallization temperature	21	ºC
Total stored heat, 30 °C to 15 °C (solidifying)	221	kJ/kg

The laboratory test with one and two thermal battery was well performed with results being compared with the 3LC test. In the 3LC, the energy stored during a heat up from 15 to 30 ºC and cooling from 30 to 15ºC are in agreement to the laboratory tests as it can be seen in Table 3. The results present an average of 105.4 Wh (± 44.5 Wh) or 4.4 % (± 6.9 %).

Table 3. Thermal load for melting and solidifying

	1 Thermal Battery				2 Thermal Batteries				
	Melting		Solidifying		Melting		Solidifying		
	EP	NP	EP	NP	EP	NP	EP	NP	Average (σ)
Laboratory test (Wh)	831.8	1015.8	-725.6	-1066.0	1472.3	2029.1	-1508.6	-2336.0	
3LC (Wh)	817.5	1059.7	828.8	1074.3	1635.0	2119.4	1657.5	2148.6	
Difference (Wh)	-14.3	43.9	103.2	8.4	162.7	90.4	148.9	-187.4	105.4 (± 44.5)
Difference	-1.7 %	4.3 %	14.2 %	0.8 %	11.1 %	4.5 %	9.9 %	-8.0 %	9.4 %(± 6.7 %)

4. Conclusions

Holding 30 % more material per thermal battery, each new panel needs more time to solidify and melt when compared to the existing panel. With results backed up by a 3LC test, the new thermal battery needs 86% more time to melt and 38% more time to solidify for 1 TB. For two TB, 100 % more time is necessary to melt and 70% to solidify. This can be explained by the 30% more material each thermal battery can hold. Furthermore, the existing thermal battery has 9 instead of 7 panels, representing a heat exchange area 28% bigger than the new thermal battery. This reduction in panels per battery module will represent a reduction in cost and maintenance for the MVS.

Acknowledgements

Thiago Santos would like to thank the Science without Borders program of CNPq - Brazil, for the funding awarded to carry out his PhD at Brunel University London (PDE: 200815/2014-8).

References

[1] Alizadeh M, and Sadrameli S M., "Development of free cooling based ventilation technology for buildings : Thermal energy storage (TES) unit , performance enhancement techniques and design considerations – A review." *Renewable and Sustainable Energy Reviews* 58(2016): 619–645. doi:10.1016/j.rser.2015.12.168.

[2] Kasaeian A, Bahrami L, Pourfayaz F, Khodabandeh E, and Yan Y-M., "Experimental studies on the applications of PCMs and nano-PCMs in buildings: A critical review." *Energy and Buildings* 154(2017): 96–112. doi:10.1016/J.ENBUILD.2017.08.037.

[3] Souayfane F, Fardoun F, and Henry Biwole P-H., "Phase change materials (PCM) for cooling applications in buildings: A review." *Energy and Buildings* 129(2016): 396–431. doi:10.1016/j.enbuild.2016.04.006.

[4] Zeinelabdein R, Omer S, and Gan G., "Critical review of latent heat storage systems for free cooling in buildings." *Renewable and Sustainable Energy Reviews* 82(October) (2018): 2843–2868. doi:10.1016/J.RSER.2017.10.046.

[5] Santos T, Kolokotroni M, Hopper N, and Yearley K., A study of panel ridges effect on heat transfer and pressure drop in a ventilation duct, in: 38th AIVC - 6th TightVent 4th Vent. Conf., 2017.

[6] Sensing Precision, . http://sensing-precision.com/wp-content/uploads/2014/12/BALANCE-MASTER-Data-Sheet.pdf (accessed June 15, 2017).

[7] Iten M, and Liu S., "Experimental Study on the Performance of RT 25 to be Used as Ambient Energy Storage." *Energy Procedia* 70(2015): 229–240. doi:10.1016/j.egypro.2015.02.119.

[8] Iten M, Liu S, and Shukla A., "Experimental study on the thermal performance of air-PCM unit." *Building and Environment* 105(2016): 128–139. doi:10.1016/j.buildenv.2016.05.035.

[9] Dolado P, Lazaro A, Marin J-M, and Zalba B., "Characterization of melting and solidification in a real-scale PCM-air heat exchanger: Experimental results and empirical model." *Renewable Energy* 36(11) (2011): 2906–2917. doi:10.1016/j.renene.2011.04.008.

[10] Osterman E, Hagel K, Rathgeber C, Butala V, and Stritih U., "Parametrical analysis of latent heat and cold storage for heating and cooling of rooms." *Applied Thermal Engineering* 84(2015): 138–149. doi:10.1016/j.applthermaleng.2015.02.081.

[11] Turnpenny J.R. R., Etheridge D.W. W., and Reay D.A., "Novel ventilation system for reducing air conditioning in buildings. Part II: testing of prototype." *Applied Thermal Engineering* 21(12) (2001): 1203–1217. doi:10.1016/S1359-4311(01)00003-5.

[12] Stritih U., and Butala V., "Experimental investigation of energy saving in buildings with PCM cold storage." *International Journal of Refrigeration* 33(8) (2010): 1676–1683. doi:10.1016/j.ijrefrig.2010.07.017.