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Thermal behavior of light earth used for building insulation: Insight on PCM introduction impact

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Abstract. To reduce building significant contribution to greenhouse gas emissions, architects and engineers are seeking eco-friendly construction solutions. Among investigated options, building's thermal insulation and heat storage can be cited.

In this regard, earth-based materials are attracting particular interest. These last years, there is a renewed interest in these eco-friendly building materials and techniques. This is due to many advantages that they present: excellent humidity regulation ability and high thermal inertia.

Present study aims to improve light earth thermal properties. Specifically, this research work focuses on the development of an insulating and heat storing material. To achieve this, phase change materials (PCM) are incorporated in soil-natural fiber mixtures.

In fact, different light earth samples are first prepared. Then, thermally characterized to highlight the impact of PCM on the light earth thermal insulating, heat storing properties and thermal response to changing boundary conditions. The incorporation of PCM showed an interesting improvement of the light earth thermal properties namely on thermal conductivity, specific heat capacity, and thermal comfort time.

Keywords: heat storage, phase change materials, light earth, thermal properties, building insulation

1. Introduction

Regarding construction industry impact on climate change, architects and construction engineers are seeking solutions to improve buildings thermal insulation and heat storage. Reducing housings energy consumption is a real challenge for researchers in the context of sustainable development. Therefore, many research have been focused on the development of energy efficient materials presenting a low environmental impact. Local and bio-based materials have attracted a particular interest [1–3].

Among these, earth-based materials can be cited. There are several construction techniques based on raw earth. Adobe, cob, light earth, wattle, and daub are the most known. These building techniques are ecological and largely widespread throughout the world. In fact, housings built with earth-based materials present a low carbon footprint and improved hygrothermal comfort [4]. They offer clear advantages such as: very good hygrothermal regulation capacity and high thermal inertia [5–8].



Phase change materials (PCMs) seem to be a promising solution within the context of sustainable construction development [9–11]. Indeed, these materials are known for their ability to store large amounts of heat when their temperature exceeds their specific melting point. The stored energy is then released during the PCM solidification. Energy stored and released by PCMs is the materials latent heat [12–14]. Incorporation of PCMs into light earth contributes to the improvement of thermal comfort by reducing the daily fluctuations of indoor temperature. Furthermore, this temperature is maintained within the thermal comfort zone for a long period [15]. This temperature stabilization is really welcomed since it prevents the use of electrical energy for heating/cooling purposes; leading to energy saving [16]. Thus, it is worth using PCM in buildings where cooling/heating is required.

Moreover, due to their thermal performances, PCMs can help to solve the problem of large wall thicknesses limiting the use of large volumes of earthen-based materials while respecting effective thermal regulations.

Present work aims to study PCMs impact on light earth thermal properties. Samples of soil-fiber-PCM mixtures were first prepared, then experimental devices were developed, and thermal measurements performed. Mixtures thermal conductivity, specific heat capacity and the thermal response to changing boundary conditions were studied.

2. Materials and methods

2.1. Materials characterization and samples preparation

Soil identification deals with grain size distribution and clay activity. The grain size distribution was performed by sieving and laser granulometry. For particles coarser than 80 μm , mechanical sieving with respect to the standard XP P94-041 [17] is used. For fine particles, a particle size analyzer (Beckman Coulter LS 13 320 laser particle size distribution) is used. Natural shaped reed raw fibers *i.e. not crushed* were cut to lengths ranging between 4 and 6 cm.

In present study, light earth is formed by mixing a crushed clay soil with not crushed reed fibers. The reed fibers mass is equal to 25 % of soil mass. PCMs were introduced into the mixtures with different contents *i.e. 5 %, 10 %, and 20 %*. PCM content is function of the soil-fiber dry mass.

The same preparation procedure is applied for all samples to be tested. After weighing, soils and PCMs are first mixed manually in a dry state using a mixer tank to ensure a homogeneous distribution. Then, the required amount of water is added, and mix is continued until the earth mixture reaches a liquid state. The fibers are then gradually incorporated. Mixing is carried out in a concrete mixer (PROVITEQ Concrete Mixer 65 L) during 2 min. At the end of mixing, the soil-fiber-PCMs mix is bagged and stored at room temperature, *i.e. 20 °C*. One day later, the mix is compacted manually with a wooden plate in pre-oiled molds. As the molds volume is known, the appropriate mix weights are calculated so as to obtain the same density. A day after compaction and molding, the samples are moved to an oven stabilized at 40 °C for two days. In the case of cylindrical samples (diameter \varnothing 11 cm x height 22 cm), molds were totally removed after these two days. Regarding prismatic samples (22 cm x 22 cm x 4 cm), molds are partially removed as follows: a side is removed every 2 days. The drying process is carried out over about 3 weeks. Before testing, pre-dried samples are placed in a room at 20 °C and 50 % relative humidity during approximately 7 days.

3. Thermal properties

3.1. Thermal conductivity

Thermal conductivity measurements are performed with an HFM 436 Lambda heat flow meter. This technique consists in establishing a temperature gradient between the two faces of the material to be tested. By measuring the heat flow and temperature gradient through the sample, thermal conductivity can be calculated using Fourier's law [18], assuming that sample dimensions are known. In present study, the measurements were carried out on 22 x 22 x 4 cm^3 prismatic samples at different average

temperatures chosen as follows: before, during, and after PCMs phase change temperature *i.e.* 14, 24 and 34 °C. Temperature difference between the specimen two sides was kept at 10 °C for each measurement.

3.2. Specific heat capacity

Specific heat capacity (Cp value) is the physical property that characterizes the ability of a material to store heat. In present study, Differential Scanning Calorimetry (DSC) technique is used to determine Cp value according to the standard ISO 11357-4 [19]. During tests, temperature was increased from -20 °C to 50 °C continuously. Heating rate was 1 °C.min⁻¹.

3.3. Thermal response to changing boundary conditions.

Thermal response to changing boundary conditions corresponds to the materials ability to buffer heat and energy consumption peaks. In other words, it is the ability of the material to stabilize indoor temperature within the thermal comfort zone.

In a first time, both sides of a studied sample (22 x 22 x 8 cm³) are exposed to a similar given thermal condition. Then, this latter was moved and placed in another ambience with different thermal conditions. Sample temperature evolution with time is followed continuously. To achieve this, T-type thermocouple has been placed within the sample core and linked to a Keithley 3706A data logger.

In a second time, both sides of the studied sample (22 x 22 x 4 cm³) are submitted to two different ambiances. To study thermal response in this case, a T-experimental device was designed and built, see Figure 1. This experimental device allows the following of samples thermal response when submitted to external temperature fluctuations. As it can be seen in Figure 1, studied sample constitutes the separation between 2 ambiances. An outside ambience (side 1) under a controlled temperature and an inside ambience (side 2) well insulated from all faces, except the one receiving the sample. Temperature of the sample inner side has been continuously followed with time. To do so, a T-type thermocouple linked to a Keithley 3706A data logger has been used. Considering that PCM phase change temperature is equal to 24 ± 2 °C, thermal cycles on side 1 have been imposed between 16 and 29 °C. The rate of temperature change is equal to 1.2 °C/h.

These measurements serve to understand how light earth-PCM mixes thermally behave and to analyze the influence of PCMs incorporation on the buildings inside temperature.

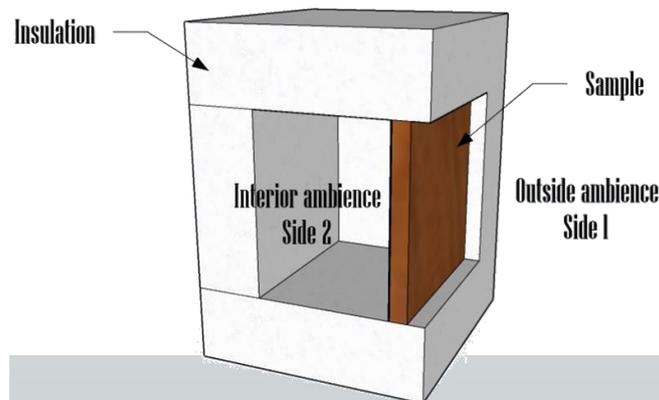


Figure 1. 3D cross-section view of T-experimental device.

4. Results and discussion

4.1. Material

Regarding soil characterization, plasticity, consistency and clay content were determined from Atterberg limits and methylene blue (MBV) value according to the standards NF P94-051 [20] and NF P94-068

[21], respectively. Liquidity limit (LL) and plasticity limit (PL) allow to estimate the earth used plasticity through plasticity index (PI). The methylene blue test gives an idea on the clay content and indicates the clay activity. Results of soil characterization are gathered in **Table 1**.

Table 1. Soil characterization.

Parameter	Soil distribution [%]		LL [%]	PL [%]	PI [%]	MBV [g/100g]
	Particle size (<2 mm)	Particle size (<80 μm)				
Soil	100	95	57.8	42.5	5.64	15.3

Selection of PCMs to incorporate into the soil-fiber mixture was made according to several factors including latent heat of phase change, chemical properties, and mainly the melting/solidification temperature. Selection of phase change temperature should take into account the notion of thermal comfort. This is dependent on many parameters, among others, typical climate conditions of the dwelling location can be cited [22]. Melting/solidification temperature must be appropriate for the local climate where the house is to be built. In France, the average temperature ranges from 0 to 30 °C over the year [23]. Consequently, to match the climate conditions to be met in France, the selection is restricted to PCMs presenting a melting temperature ranging between 5 and 25 °C. Also, for human thermal comfort, the phase-change temperature of PCMs should range approximately between 16 and 25 °C [24]. Microencapsulated PCMs are preferable to bulk PCMs since they prevent leakage when it melts and have a larger heat transfer surface area per unit volume [25]. Considering the above-mentioned criteria and commercial availability, the PCM Nextek 24D has been selected. Its phase change temperature is supposed equal 24 ± 2 °C [26].

4.2. Thermal conductivity

Thermal conductivity versus PCMs content is given for 3 average temperatures. From **Figure 2**, it can be clearly observed that the reference sample (without PCM) presents a thermal conductivity increasing with temperature. Also, addition of PCM decreases light earth thermal conductivity. When temperature is outside the phase change zone, a 5 % reduction is obtained whatever the PCM content. This reduction in thermal conductivity is supposed due to the weak thermal conductivity of PCMs themselves. Within phase change zone, there is 9 %, 13 %, and 14 % reduction for 5 %, 10 %, and 20 % PCM content, respectively. This is supposed due to the increase of disorder during PCM melting/solidification phenomena. No significant reduction is observed when PCM content is between 10 % and 20 %. Perhaps this is a sign that an optimal PCMs content exist. To confirm this assumption, overall samples thermal behavior must be analyzed.

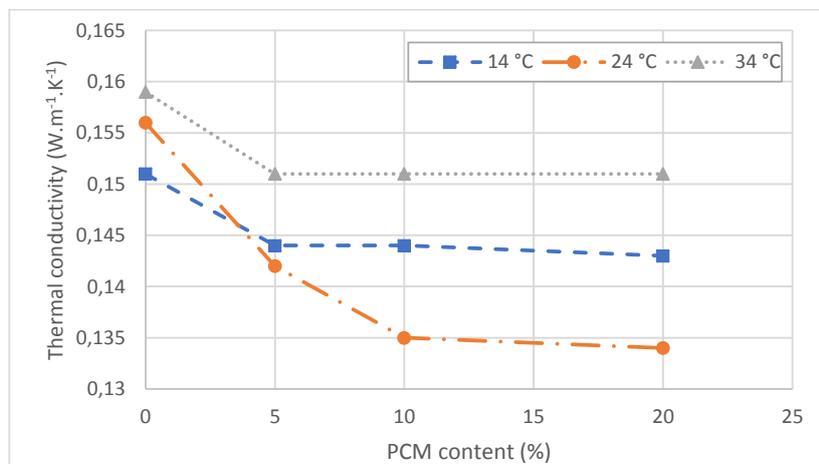


Figure 2. Light earth thermal conductivity vs PCM content at three different temperatures.

4.3. Specific heat capacity

Figure 3 shows the evolution of samples specific heat capacity as function of PCMs content at 3 different temperatures: 14 °C, 24 °C and 34 °C. Cp value seems to similarly vary above and under the melting temperature *i.e. both sides of the phase change temperature*. Addition of PCMs increases more or less the Cp value of light earth mixtures. In fact, before phase change temperature (14 °C), samples specific heat capacity for 5 %, 10 %, and 20 % added PCM is respectively 1.04, 1.07, and 1.13 times higher than the one of the reference sample (light earth without PCM). It is observed approximately similar increase after phase change temperature (34 °C). During phase change, and at the peak value of 24 °C, Cp values of the samples containing 5 %, 10 %, and 20 % PCM are respectively 3, 5.7 and 10.4 times higher than the one of the reference sample. This important increase in specific heat capacity results in a combination of the latent heat of phase change and materials sensible heat.

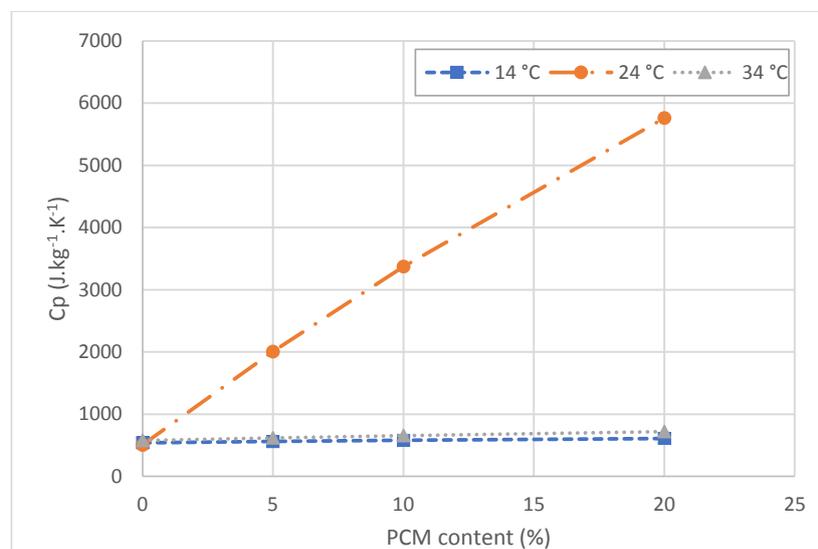


Figure 3. Light earth specific heat capacity vs PCM content at three different temperatures.

4.4. Thermal response to changing boundary conditions.

The response of light earth samples to a change in boundary conditions (temperature) was first investigated. **Figure 4** shows variation of samples temperature placed initially at 35 °C and subsequently at 10 °C. The main observation concerns the presence of a stage *i.e. constant level*. This constant level appears at temperatures between 22 °C and 23 °C and represents the melting point of PCMs incorporated in light earth. Phase change temperature is approximately 1,5 °C less than 24 °C given by the supplier, but it is within uncertainty range.

Furthermore, curves slopes are supposed related to materials thermal conductivity. When thermal conductivity decreases, more time is needed for samples heating/cooling. Considering studied light earth samples, time required for cooling increases with PCMs content. To slope down temperature from 35 °C to 10 °C, 2h13min are necessary for reference sample while 2h54min, 3h8min, and 4h17min are needed for samples with 5 %, 10 %, and 20 % of added PCMs, respectively. This increase in spent time will certainly influence sample thermal response when outside temperature changes and fluctuates.

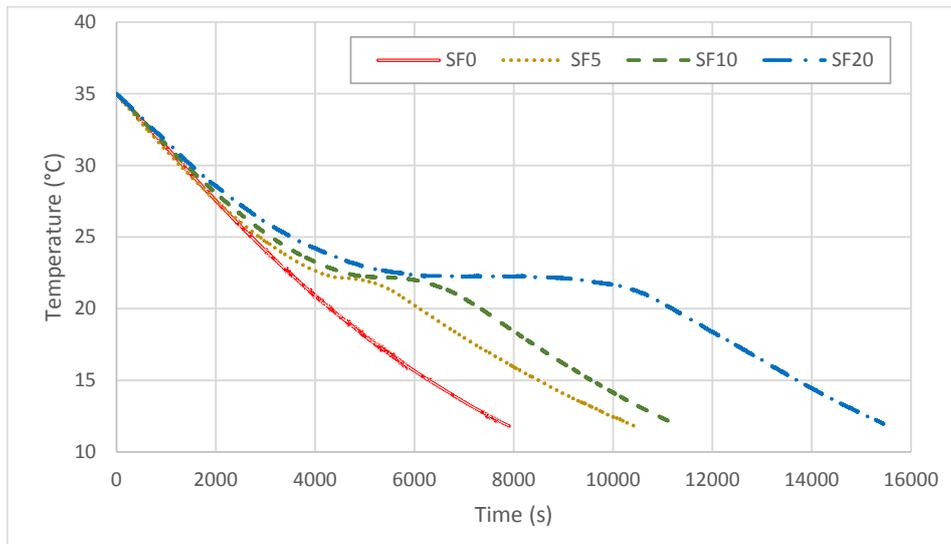


Figure 4. Evolution of light earth-PCM temperature with time (SF*i*: S = Soil, F = Fiber, and i = PCM content).

When outside temperature is cycled (dashed lines in **Figure 5**), samples inner side temperature evolves as shown in **Figure 5**. First, presence of a light earth sample modifies amplitude and wavelength of the applied temperature cycle. Then, when considering inside temperature, cycles amplitude decreases slightly. A maximal reduction of 0.5 °C can be observed. Also, temperature peaks are time shifted. This shift is clearly dependent on PCM content and is greater when temperatures are below the melting point. For samples with PCM content of 10 % and 20 %, peaks are shifted by 1h17min and 1h50 min, respectively. When temperatures are above the PCM melting point, a peak shift of approximately 20 min and 40 min is estimated for samples with 10 % and 20 % PCM content, respectively. In the case of the sample with 5 % added PCMs, no significant shift was observed.

Moreover, advantage of PCMs incorporation into light earth is also demonstrated by the time elapsed around the phase change temperature. If we consider that PCM melting point at approx. 22.5 °C is within a thermal comfort zone comprised between 21 °C and 24 °C, time spent within this zone is improved. More light earth PCM content is important, more time spent within this thermal comfort zone is higher. In fact, time spent between 21 °C and 24 °C increases from 3h24min for reference sample to 3h48 min, 4h44min and 5h18min for PCM content of 5 %, 10 % and 20 %, respectively. Considered temperatures have been measured at the samples inner surface.

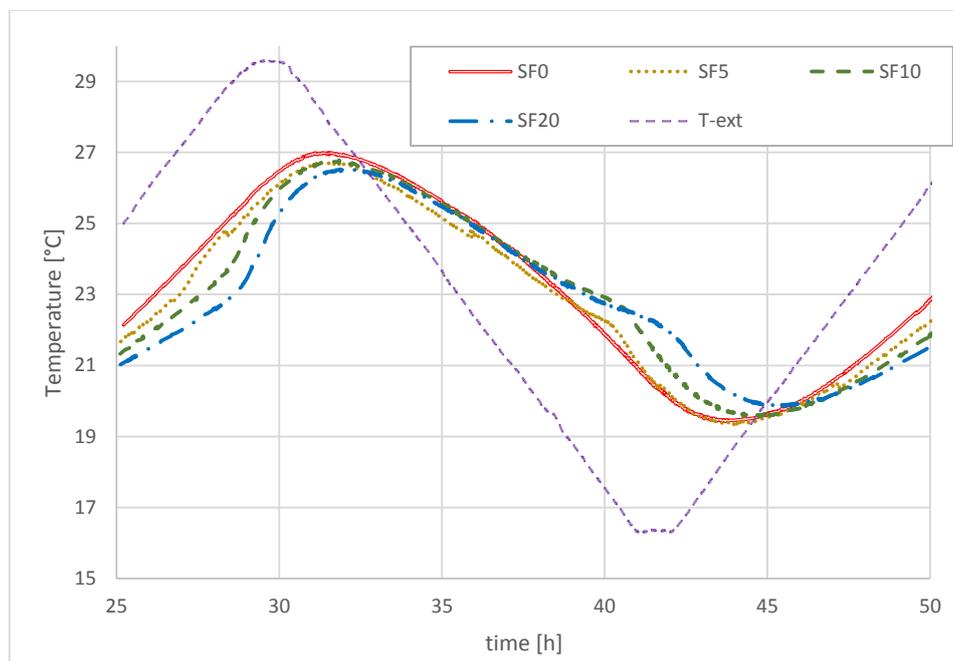


Figure 5. Evolution of light earth-PCM temperature with time under thermal cycling conditions. Heating/cooling rate is equal to 1.2 °C/h.

5. Conclusion

In present study, impact of PCMs incorporation on the thermal properties of light earth was investigated. Light earth samples with various PCM content were elaborated. Samples thermal conductivity, specific heat capacity and thermal response to changing boundary conditions were studied.

Results analysis showed that samples thermal conductivity is reduced when PCM content increases. This is assumed due to the low PCM thermal conductivity. At phase change temperature, the light earth sample with 20% PCM was approximately 14% less conductive than the sample without PCM.

PCM incorporation had a significant impact on light earth specific heat capacity. In fact, Cp value increases linearly with the PCM content. Near phase change temperature, when light earth PCM content is equal to 20%, Cp value is 10 times larger than the one of the samples without PCM.

Also, PCM impact notably the mixtures thermal response to changing boundary conditions. In fact, a decrease in temperature oscillations amplitude, a shift of temperature peaks and an increase of time elapsed within the thermal comfort zone have been observed. Combining all these properties, it can be stated that addition of PCMs into light earth will eventually improve the feeling of comfort in houses that would be built with this kind of mixture.

PCM would raise the construction cost as it is more expensive than light earth. A calculation may be done to estimate time required to offset the increase in construction cost through energy consumption savings. It could be based on different scenarios *i.e. location, climate, etc.*

As a conclusion, it can be stated that the incorporation of phase change materials into the light earth improves its insulation level and heat storage capacity. Indoor thermal comfort of building made with light earth incorporating PCM can also be notably improved. Finally, to precisely assess energy saving and thermal comfort improvement, that can be allowed by PCM incorporation into light earth, further cell-scale experimental and numerical studies are being considered for our future studies.

References

- [1] A. Laborel-Préneron, J.E. Aubert, C. Magniont, C. Tribout and A. Bertron, Plant aggregates and fibers in earth construction materials: A review, *Constr. Build. Mater.* 111 (2016) 719–734. <https://doi.org/10.1016/j.conbuildmat.2016.02.119>.
- [2] G. Giuffrida, R. Caponetto and F. Nocera, Hygrothermal Properties of Raw Earth Materials: A Literature Review, *Sustainability*. (2019). <https://doi.org/10.3390/su11195342>.
- [3] H. Karaky, *Élaboration et caractérisation physique et hygrothermique d'un agro-matériau à base de pulpe de betterave et d'amidon.*, These de doctorat, Reims, 2018. <http://www.theses.fr/fr/2018REIMS019> (accessed February 4, 2021).
- [4] R. Anger, L. Fontaine, T. Joffroy and E. Ruiz, Construire en terre, une autre voie pour loger la planète, *Sect. Privé Dév. Rev. Bimest. Proparco*. 10 (2011) 18–21.
- [5] T. Colinart, T. Vincelas, H. Lenormand, A.H.D. Menibus, E. Hamard and T. Lecompte, Hygrothermal properties of light-earth building materials, *J. Build. Eng.* 29 (2020) 101134. <https://doi.org/10.1016/j.job.2019.101134>.
- [6] S. Goodhew, J. Carfrae, K. Hood-Cree, M. Fox, M. Boutouil and F. Streiff, Building with earth: How we are working to revive an ancient, sustainable building technique, *Constr. Res. Innov.* 10 (2019) 105–108. <https://doi.org/10.1080/20450249.2019.1700077>.
- [7] T.A. Phung, *Formulation et caractérisation d'un composite terre-fibres végétales: la bauge*, PhD Thesis, Normandie Université, 2018. <https://tel.archives-ouvertes.fr/tel-01938827> (accessed January 5, 2021).
- [8] K. Holzhueter and K. Itonaga, The Potential for Light Straw Clay Construction in Japan: An Examination of the Building Method and Thermal Performance, *J. Asian Archit. Build. Eng.* 16 (2017) 209–213. <https://doi.org/10.3130/jaabe.16.209>.
- [9] A. Pasupathy, R. Velraj and R.V. Seeniraj, Phase change material-based building architecture for thermal management in residential and commercial establishments, *Renew. Sustain. Energy Rev.* 12 (2008) 39–64. <https://doi.org/10.1016/j.rser.2006.05.010>.
- [10] C. Chen, H. Guo, Y. Liu, H. Yue and C. Wang, A new kind of phase change material (PCM) for energy-storing wallboard, *Energy Build.* 40 (2008) 882–890. <https://doi.org/10.1016/j.enbuild.2007.07.002>.
- [11] A.K. Athienitis, C. Liu, D. Hawes, D. Banu and D. Feldman, Investigation of the thermal performance of a passive solar test-room with wall latent heat storage, *Build. Environ.* 32 (1997) 405–410. [https://doi.org/10.1016/S0360-1323\(97\)00009-7](https://doi.org/10.1016/S0360-1323(97)00009-7).
- [12] C. Barreneche, M.E. Navarro, A.I. Fernández and L.F. Cabeza, Improvement of the thermal inertia of building materials incorporating PCM. Evaluation in the macroscale, *Appl. Energy*. 109 (2013) 428–432. <https://doi.org/10.1016/j.apenergy.2012.12.055>.
- [13] L. Haurie, S. Serrano, M. Bosch, A.I. Fernandez and L.F. Cabeza, Single layer mortars with microencapsulated PCM: Study of physical and thermal properties, and fire behaviour, *Energy Build.* 111 (2016) 393–400. <https://doi.org/10.1016/j.enbuild.2015.11.028>.
- [14] V.V. Tyagi and D. Buddhi, PCM thermal storage in buildings: A state of art, *Renew. Sustain. Energy Rev.* 11 (2007) 1146–1166. <https://doi.org/10.1016/j.rser.2005.10.002>.
- [15] L.F. Cabeza, C. Castellón, M. Nogués, M. Medrano, R. Leppers and O. Zubillaga, Use of microencapsulated PCM in concrete walls for energy savings, *Energy Build.* 39 (2007) 113–119. <https://doi.org/10.1016/j.enbuild.2006.03.030>.
- [16] A. Pasupathy, L. Athanasius, R. Velraj and R.V. Seeniraj, Experimental investigation and numerical simulation analysis on the thermal performance of a building roof incorporating phase change material (PCM) for thermal management, *Appl. Therm. Eng.* 28 (2008) 556–565. <https://doi.org/10.1016/j.applthermaleng.2007.04.016>.
- [17] Soil : investigation and testing. Granulometric description. Wet sieving method., XP P94-041, 1995. <https://sagaweb.afnor.org>.
- [18] J.W. Gooch, Fourier's Law of Heat Conduction, in: J.W. Gooch (Ed.), *Encycl. Dict. Polym.*, Springer, New York, NY, 2011: pp. 323–323. https://doi.org/10.1007/978-1-4419-6247-8_5262.
- [19] Plastiques — Analyse calorimétrique différentielle (DSC) — Partie 4 : Détermination de la capacité thermique massique, NF EN ISO 11357-4, 2014. <https://sagaweb.afnor.org/>.

- [20] Soil : investigation and testing. Determination of Atterberg's limits. Liquid limit test using cassagrande apparatus. Plastic limit test on rolled thread., NF P94-051, 1993. https://cobaz.afnor.org/notice/norme/nf-p94-051/FA020765?rechercheID=795218&searchIndex=1&activeTab=all#id_lang_1_descripteur.
- [21] Soils : investigation and testing. Measuring of the methylene blue adsorption capacity of a rocky soil. Determination of the methylene blue of a soil by means of the stain test., NF P94-068, 1998. <https://sagaweb.afnor.org>.
- [22] M. Kheradmand, M. Azenha, J.L.B. de Aguiar and J. Castro-Gomes, Experimental and numerical studies of hybrid PCM embedded in plastering mortar for enhanced thermal behaviour of buildings, *Energy*. 94 (2016) 250–261. <https://doi.org/10.1016/j.energy.2015.10.131>.
- [23] Météo France, (2019). <http://www.meteofrance.fr/climat-passe-et-futur/bilans-climatiques/bilan-2019/bilan-climatique-de-l-ete-2019#> (accessed October 21, 2020).
- [24] A. Sari, A. Karaipekli and K. Kaygusuz, Capric acid and stearic acid mixture impregnated with gypsum wallboard for low-temperature latent heat thermal energy storage, *Int. J. Energy Res.* 32 (2008) 154–160. <https://doi.org/10.1002/er.1352>.
- [25] S. Park, Y. Lee, Y.S. Kim, H.M. Lee, J.H. Kim, I.W. Cheong and W.-G. Koh, Magnetic nanoparticle-embedded PCM nanocapsules based on paraffin core and polyurea shell, *Colloids Surf. Physicochem. Eng. Asp.* 450 (2014) 46–51. <https://doi.org/10.1016/j.colsurfa.2014.03.005>.
- [26] C. Group, Microtek Laboratories, (2020). <https://www.microteklabs.com> (accessed October 22, 2020).