PHASE CHANGE MATERIALS FOR IMPROVING THE THERMAL PERFORMANCE OF LSF CONSTRUCTION

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Abstract *Energy is nowadays a prime concern of our society and the buildings' sector is an important player regarding energy consumption. Energy efficiency and the use of renewable energy sources are two strategies implemented by European Directives to address the energy performance of buildings. The research project PCMs4Buildings – Systems with PCM-filled rectangular cavities for the storage of solar thermal energy for buildings – was funded by FCT and by FEDER/COMPETE2020/POCI. The main goal of this research project is the development of systems with PCM-filled rectangular cavities for the storage of solar thermal energy in order to enhance the energy performance of buildings. Given their reduced thermal mass, lightweight steel framed (LSF) buildings are very suitable for the use of phase change materials (PCMs). Therefore, the PCMs4Buildings project mainly focuses on LSF construction, namely in the scope of Task 4 – "Tests in the Guarded Hot Box Apparatus" and of Task 5 – "Definition of full-scale prototypes". In this communication it will be described the research activities related with Task 4 and the obtained results, as well as the future work.*

1. INTRODUCTION

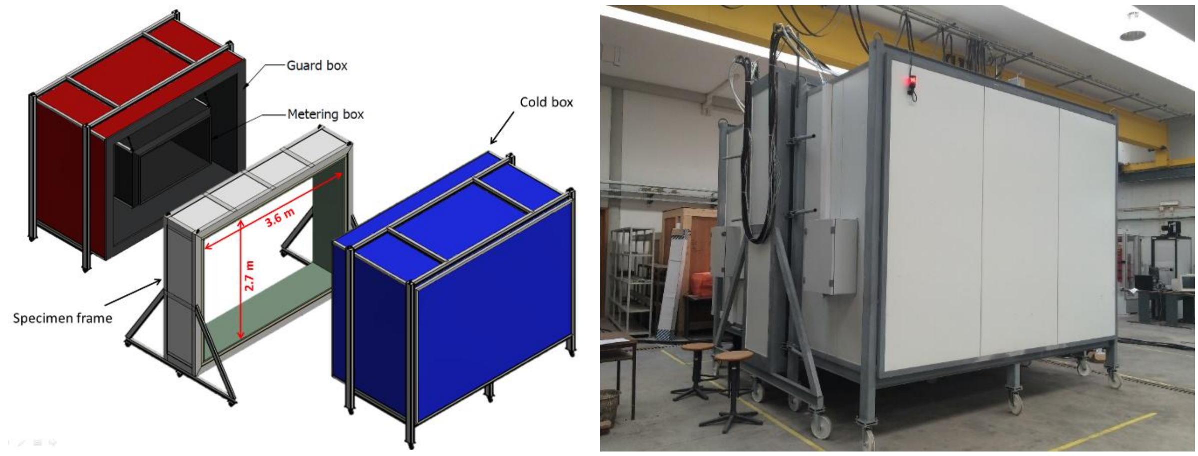
The aim to increase energy efficiency of buildings and to make use of renewable energy sources, including passive technologies (*e.g.* making use of solar heat gains), has fostered the researchers to study, develop and implement several strategies to achieve this goal. Several research projects have been funded with these purposes. *PCMs4Buildings* [1] is a research project funded by the Portuguese foundation for science and technology (FCT) and by European funds (FEDER/COMPETE2020/POCI). The main goal of this research project is to improve the energy efficiency of buildings by making use of solar thermal energy stored in rectangular cavities filled with PCMs. Given its advantages described in refs. [2,3], and due to its light-weightiness and consequent reduced thermal mass, LSF buildings are very appropriate for the use of PCMs. Thus, the *PCMs4Buildings* project mainly focuses on LSF construction regarding real-scale research. The main goal of this communication is to present the research activities related with Task 4 – *"Tests in the Guarded Hot Box"*, describing the tests already performed and the achieved results. After this brief introduction, the main tasks of the *PCMs4Buildings* project are listed. Then, the (guarded) hot box apparatus is described and the experimental tests already accomplished are described and the obtained results presented. Next, several 2D and 3D numerical simulations are presented and the obtained results commented. Afterwards, a comparison between the experimental and the numerical results is made. To conclude this communication, some final remarks and future works are presented.

2. PCMS4BUILDINGS RESEARCH PROJECT

The research plan of the project *PCMs4Buildings* is composed by six main tasks [1], namely: (1) thermophysical characterization of PCMs; (2) numerical modelling and CFD evaluation; (3) tests in the small-scale experimental setup; (4) tests in the guarded hot box apparatus; (5) definition of full-scale prototypes; (6) technical seminar and workshop. This work will be mainly focussed on Task 4 related research activities and obtained results.

3. (GUARDED) HOT BOX APPARATUS

The guarded hot box apparatus was designed and assembled at ISISE-DEC/FCTUC during a PhD work by Cláudio Martins, taking into account the prescriptions provided by EN ISO 8990 [4]. It allows measuring the thermal transmittance (*U*-value) of heterogeneous walls at real-scale test-specimens, up to 3.6W × 2.7H × 0.4T (m), as illustrated in Figure 1. Unfortunately, several problems have arisen during the calibration process, with consequent delays in the experimental campaign and meanwhile the equipment has been used as climatic chambers: hot and cold boxes, instead of a guarded hot box. Therefore, as an alternative to the metering box, the thermal performance of the LSF walls is measured locally using heat flux sensors and thermocouples. Given the above mentioned delays it was not possible yet to measure the thermal performance of LSF walls with PCMs.



(a) Sketch of the main components (b) Photo of the equipment in the laboratory

Figure 1. (Guarded) hot box apparatus.

4. EXPERIMENTAL TESTS

The test procedures to measure the thermal performance of the LSF walls followed the prescriptions provided by several international standards, namely ISO 9869:1994 [5], ASTM C 1155-95 [6] and ASTM C 1046-95 [7]. Until now, four different wall configurations were tested, as illustrated in Figure 2, and three tests were performed for each wall configuration. The 10 cm-thick XPS wall panel was tested to verify the test procedures and evaluate its accuracy, since the thermal conductivity of the XPS material is known (0.036 W/(m·°C)). The average difference between the measured thermal conductivity and the value provided by the manufacturer was +5%, which is acceptable given the sensors precision and other uncertainties.

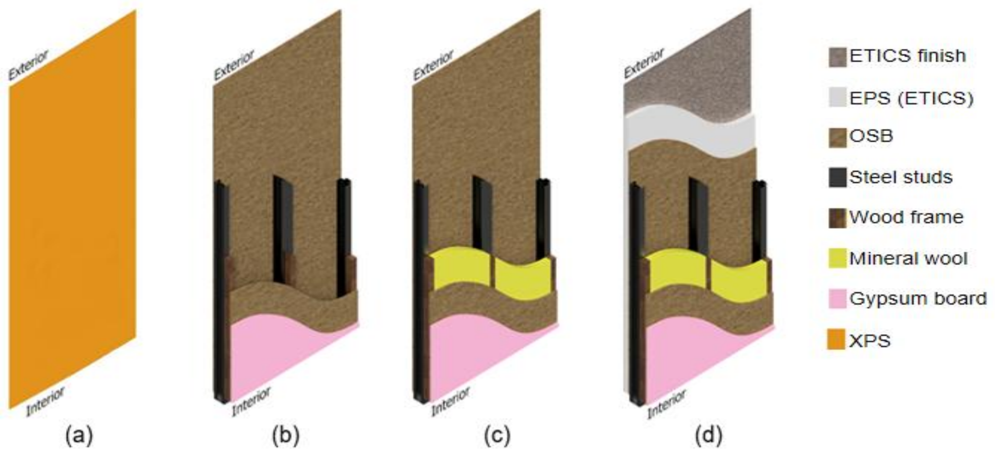


Figure 2. Tested walls: (a) homogeneous XPS panel; and heterogeneous LSF walls: (b) without thermal insulation; (c) with mineral wool (MW) in the air-cavity; (d) with MW in the air-cavity and ETICS.

Table 1 presents the thermal transmittance values obtained for the LSF walls using the data recorded during the experimental tests. The wood bars allowed to reduce the thermal bridge effect originated by the steel studs. The overall weighted *U*-value for the LSF wall without thermal insulation was 1.480 W/(m^2·°C). The addition of 5 cm MW to the air-cavity allowed to significantly reduce the thermal transmittance of the wall (-52%). Given the thermal insulation continuity of the ETICS, the steel studs thermal bridge effect was reduced, resulting in *U*-values between and near the steel profiles closer to each other. The obtained overall *U*-value of this 3rd wall was 0.324 W/(m^2·°C).

Table 1. *U*-values obtained for the LSF walls based on experimental data.

Wall typology	**Thermal transmittance, *U*** [W/(m^2·°C)]			
	Between steel studs 0	**Near steel studs 1**	**Near steel studs 2**	**Overall weighted value**
1-Without thermal insulation	1.568	1.041	1.203	**1.480**
2-With Mineral Wool (MW) in air-cavity	0.658	0.788	1.128	**0.711**
3-With MW in air-cavity and ETICS	0.279	0.363	0.470	**0.324**

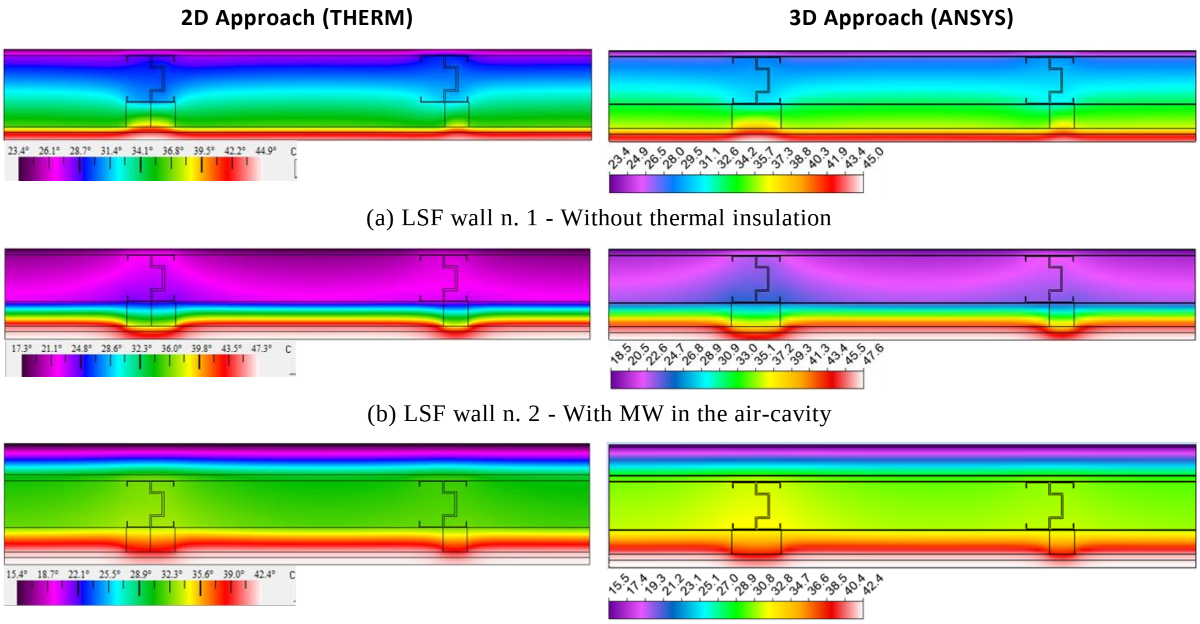
5. NUMERICAL SIMULATIONS

The three LSF walls were modelled in a 2D (THERM) and a 3D (ANSYS) simulation software, based on the finite elements method. To minimize the computer resources needed for the 3D simulations, only a representative part of the total tested wall modules was modelled (1.20W × 1.25H m). The boundary conditions for the wall hot and cold surfaces (ambient temperatures and surface thermal resistances) were obtained from the experimental tests (average values were used). Moreover, several adiabatic surfaces were used, including the border boundaries of the calculation domain in the 3D model. The values of the material properties (*e.g.* thermal conductivity) used in the simulations were provided by the manufacturers or taken from databases (standard values).

Figure 3 displays the temperature distributions predicted by the 2D (THERM) and 3D (ANSYS) simulations along a horizontal cross-section of the LSF walls. A very good agreement is observed between the two numerical approaches. Moreover, these plots allow to confirm the steel studs thermal bridge mitigation effect provided by the wood bars (LSF wall n.1) and by the ETICS (LSF wall n.3).

6. COMPARISON BETWEEN EXPERIMENTAL AND NUMERICAL RESULTS

Table 2 presents the *U*-values provided by the measured data from the experiments (Exp.) and by the 3D (ANSYS) and 2D (THERM) numerical predictions. The differences between the predictions and the measurements are quite small ([0.018; 0.130] W/(m^2·°C) or [4.8; 18.3] %). These errors could be due to sensors imprecision, inaccuracy in the sensors location, workmanship imperfections, joints between panels that were not modelled, neglected convection effects inside the air-cavity, etc. These differences are greater for the LSF wall n.2 with 5 cm MW in the air-cavity. This can be due to possible workmanship imperfections during the colocation of the MW in the air-cavity. For this simple configuration of LSF walls (with only vertical steel studs in the metering area) the accuracy of 2D and 3D models is very similar.



(a) LSF wall n. 1 - Without thermal insulation

(b) LSF wall n. 2 - With MW in the air-cavity

(c) LSF wall n. 3 - With MW and ETICS

Figure 3. Cross-section temperatures predicted by 2D and 3D numerical simulations.

Table 2. Experimental and numerical *U*-values obtained for the LSF walls.

	Wall n.1 - Without Thermal Insulation			**Wall n.2** - With Mineral Wool (MW)			**Wall n.3** - With MW and ETICS		
	Exp.	**ANSYS**	**THERM**	**Exp.**	**ANSYS**	**THERM**	**Exp.**	**ANSYS**	**THERM**
***U*-value** [W/m^2/°C]	1.480	1.409	1.399	0.711	0.598	0.581	0.324	0.346	0.306
Absol. Diff.	---	-0.071	-0.081	---	-0.113	-0.130	---	+0.022	-0.018
Perc. Diff.	---	-4.8%	-5.5%	---	-15.9%	-18.3%	---	+6.8%	-5.6%

7. FINAL REMARKS AND FUTURE WORK

In this short paper, the research activities related with Task 4 of the project *PCMs4Buildings* were presented, as well as the obtained preliminary results. As ongoing work, some tests will be performed with the same LSF wall module adding a layer of PCM containing material. Other LSF walls prototypes, with a more complex structure, will also be tested.

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