1. INTRODUCTION

Phase Change Materials (PCMs) have been considered for thermal storage in buildings since before 1980. With the advent of PCM implemented in gypsum board, plaster, concrete or other wall covering materials, thermal storage can be part of the building structure even for lightweight buildings.

In the literature, development and testing were conducted for prototypes of PCM wallboard and PCM concrete systems to enhance the thermal energy storage (TES) capacity of standard gypsum wallboard and concrete blocks, with particular interest in peak load shifting and solar energy utilization.

During the last 20 years, several forms of bulk encapsulated PCM were marketed for active and passive solar applications, including direct gain. However, the surface area of most encapsulated commercial products was inadequate to deliver heat to the building after the PCM was melted by direct solar radiation. In contrast, the walls and ceilings of a building offer large areas for passive heat transfer within every zone of the building (Neeper, 2000). Several authors have investigated methods for impregnating gypsum wallboard and other architectural materials with PCM (Salyer et al., 1985; Shapiro et al., 1987; Babich et al., 1994; Banu et al., 1998). Different types of PCMs and their characteristics are described. The manufacturing techniques, thermal performance and applications of gypsum wallboard and concrete block, which have been impregnated with PCMs, have been presented and discussed previously (Khudhair and Farid, 2004; Zalba et al., 2003; Hauer et al., 2005).

This study investigates the effect of microencapsulated PCM mixed with concrete on the thermal performance of a small house-sized cubicle located in Lleida (Spain). This work was developed under the EU project MOPCON with partners from Spain, The Netherlands, Greece, and France.

2. EXPERIMENTAL SETUP

This study investigates the inclusion of PCM in concrete. An innovative concrete with PCM was developed using a commercial microencapsulated PCM, with a melting point of 26°C and a phase change enthalpy of 110kJ/kg. Mechanical strength tests of this new concrete showed lower compressive and flexural strength values than normal concrete, but they still fulfil requirements for non-structural and structural walls. In the latter case, though, they are not recommended as the values are too close to the current lower limits. Further improvements to increase the mechanical properties of this new concrete with PCM are expected.

This novel concrete was used in the construction of a small house-sized cubicle; south, west and roof walls were constructed with the new concrete. The cubicle was fully instrumented to monitor and evaluate the thermal characteristics: temperature sensors in every wall, temperature sensors in the middle of the room at heights of 1.2 m and 2.0 m, and one heat flux sensor in the inside wall of the south panel.
A second cubicle with the exact same characteristics and orientation, but built with standard concrete, was located next to the first one as the reference case. In this way conventional elements and the new developments are being tested simultaneously.

A meteorological station was installed nearby and one irradiation sensor on top of each cubicle give the irradiation measures, and also the possibility of shadows in each one (Figure 1 and Figure 2). All the instrumentation is connected to a data logger connected to a computer to work with the obtained data.

3. RESULTS

During summer and autumn 2005, the behaviour of such cubicles was tested. Results were in good agreement with the expected enhanced performance of the PCM cubicle. In Figure 3 it can be highlighted that while the maximum outdoors temperature was 32°C, the west wall of the cubicle without PCM reached 39°C, and the west wall of the cubicle with PCM reached only 36°C, showing a temperature difference of 3°C. This difference could also be seen in the minimum temperatures.

To see details in the experiments, the measurements of three days for the west wall are presented in Figure 4.
Figure 3: Ambient temperature and temperatures of the west wall with and without PCM with closed windows tests in August 2005.

Figure 4: Detail of the west wall temperatures and ambient temperature with closed windows tests in August 2005.

Another important parameter measured was the heat flux in the south wall (Figure 5).
Other different situations were tested, namely the effect of opening windows all day, and the effect of opening windows only at night, as a free cooling system (Figure 6 and Figure 7).

Figure 5: Comparison between south wall temperatures in both cubicles, outdoors ambient temperature, and heat flux. **Closed windows** tests in August 2005.

Figure 6: Comparison between south wall temperatures in both cubicles, outdoors ambient temperature, and heat flux of both cubicles. **Case Opened windows**, tests in July 2005.
A new series of experiments was performed where blinds (Figure 8) were added to the south-oriented windows.

The same experiments as before were performed in this case; Figure 9 shows the results with the windows opened and Figure 10 shows results for the case of opening the windows in the evening and closing them during the day.
Figure 9: Comparison between west wall temperatures in both cubicles, and outdoors ambient temperature. **Case Open windows with blinds**, tests in August 2005.

Figure 10: Comparison between west wall temperatures in both cubicles, and outdoors ambient temperature. **Case Opening and closing windows with blinds**, tests in August 2005.

Figure 11 (case with blinds) and Figure 12 (case without blinds) illustrate how the observed sharp indoors temperature peaks due to direct solar radiation (Figure 12) disappear when the blinds are used (Figure 11).
4. DISCUSSION

The comparison among all experiments is quite difficult, due to the amount of data generated. Therefore, only the main differences will be highlighted here.

When comparing the temperatures in the experiments, it can be seen that in all cases the effect of the PCM is present in the walls which contain PCM, with wall temperature differences of 2 to 3°C. The maximum temperature in the wall with PCM appears about 2 hours later than in the one without PCM, i.e., the thermal inertia of the wall is higher. This thermal inertia appears in the afternoon due to the freezing of the PCM, but also earlier in the morning due to the melting of the PCM. The morning temperatures are approximately the same in both cubicles (Figure 3 to Figure 10), but the temperatures show differences in the cooling down in the afternoon. The main difference is that when the windows are opened (continuously), the thermal inertia due to the freezing of the PCM is not so obvious (Figure 9). Thus the user behaviour will be an important issue with respect to thermal behaviour of the buildings, the PCM performance and the potential energy savings.

The heat flux in the south wall in the experiments follows the same patterns, the heat flux has the same tendency in both cubicles when the PCM is out of its melting/freezing zones, but changes totally its behaviour when there is a phase change (Figure 5, Figure 6 and Figure 7).

The thermal inertia seen in all the experiments shows that all the PCM included in the cubicle walls freezes and melts in every cycle. There results also showed that night cooling is important to achieve this full cycle every day.

The main problem with the windows with no blinds was that at some point of the day the inside temperature of the cubicles did rise unexpectedly, and visual observation showed that this was due to the solar radiation reaching directly the temperature sensor. This has been demonstrated with the experiments with blinds, since in these cases, the temperature peaks disappear (Figure 11 and Figure 12).

5. FUTURE WORKS

A Trombe wall (Figure 13) was recently added to the south façade to investigate if the effect of the PCM can be used all year long in Mediterranean weathers to reduce both cooling and heating demands. Other effects such as the inclusion of an interior sensible thermal load (a person or a computer in the building) or the installation of a autonomous heat pump that controls the indoor temperature will be tested in the near future.
CONCLUSION

The final objective of this work is the development of an innovative concrete with phase change materials (PCM) that enhances thermal inertia and could achieve important energy savings in buildings. The work here presented is the experimental study of two real size concrete cubicles, one of which includes PCM in some walls. This PCM has a melting point of 26°C, and a phase change enthalpy of 110 kJ/kg.

The cubicles were installed in the town of Puigverd of Lleida (Spain). The results of this study show the energy storage in the walls by encapsulating PCMs and the comparison with conventional concrete without PCMs, leading to an improved thermal inertia as well as lower inner temperatures. These results demonstrate a real opportunity for air-conditioning energy savings in buildings during the spring and summer seasons.

The thermal inertia seen in all the experiments suggests that all the PCM included in the cubicle walls freezes and melts in every cycle. These results also showed that night cooling is important to achieve this full cycle every day.

ACKNOWLEDGMENTS

The authors would like to acknowledge the contribution of all the partners of the MOPCON project (EU CRAFT ref. G5ST-CT-2002-50331): Aspica Constructora (coordinator-Spain), University of Lleida (Spain), Inasmet (Spain), BSA (Spain), Medysys (France), Prokel (Greece), and Intron (The Netherlands).

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