Improvement of Cladding Insulation Panels for Sustainable Buildings

Thermal performance evaluation of composite insulating material

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ABSTRACT: Quality of a cladding system can be improved through the enhancement of its insulating components. Thermal insulation performance of buildings envelope affects indoor comfort and energy consumption of heating and cooling systems. Specifically during summertime, envelopes characterized by good thermal conductivity are not efficient enough to minimize the heat transfer through the wall. Due to these reasons, insulating materials with high heat accumulation properties have been widely investigated in recent years. Among these substances Phase Change Materials (PCMs) are able to store high amount of heat at predetermined temperatures exploiting their latent heat.
Starting from the development of a new composite material made of recycled cardboard and PCMs, the present work aims to verify, through laboratory tests, the sustainability improvements resulting from the use of this composite material as a thermal insulating envelope.
The environmental improvements obtained with the product development are: the use of a widely available waste product as base material; the development of a new smart material able to increase the insulation properties at specific conditions using PCMs; the achievement of a product which turns recyclable. Results have shown the possibility to improve in dynamic thermal conditions the insulating properties of building envelopes.

Keywords: PCMs; Cellulose insulation; Building envelope.

INTRODUCTION

Several factors affect the sustainability of a building. One of them is the energy consumption caused by air conditioning systems. These facilities, once mainly placed in commercial or public buildings, are becoming more and more common also in private houses. Specifically in the areas characterized by a Mediterranean climate, the energy consumption for cooling systems represents an economical and environmental problem due to overheating during summertime and because of the growing request of indoor wellness. [1]

The project of a sustainable building cannot be detached from the study of its envelope stratification. Walls composition and the properties of each material determine the insulating performance of the entire building and are responsible of heat flows between the outside environment (where atmospheric conditions affect the climate) and the inside spaces (where wellness feeling are necessary to carry out indoor activities). [2]

In order to improve the sustainability of a building, it is possible to focus on the study of its individual components. In the present research, the work focuses on the thermal performance of insulating panels and their environmental impact: the aim is to reduce the needs of air conditioning during the summertime specifically in Mediterranean countries, thanks to the use of innovative insulating panels.

A possible solution to the problem concerns the implementation of thermal storage performance of envelopes, which can be achieved in two ways: using thick components with high specific heat, c [J/(kg K)], and high density, ρ [kg/m^3], or using materials with high latent heat, Δh [J/kg]. The second idea has been widely investigated in recent years using Phase Change Materials (PCMs) because of their capacity to store high amount of energy during their phase transition. [3]

Due to their high heat storage capacity, PCMs placed inside lightweight prefabricated help decreasing thermal peaks inside rooms and reducing energy consumption required by cooling systems. [4]

MATERIALS

Object of the present study is a new insulating panel developed in previous research: a composite material made of cellulose fibres (derived from waste cardboard), paraffine PCMs and additives [5].

The composite material has been realized with two different types of paraffine PCMs: Rubitherm PX28HC, with phase transition at 28°C, and Micronal Basf DS600, with phase transition at 26°C. [6]
Further additives have been inserted into the cellulose matrix in order to improve water and fire resistance properties: they are anti-moisture Basoplast Basf and fire retardant Borate Salts, respectively. [7]
All the samples realized have been subjected to thermal tests in order to evaluate their impact on energy consumption caused by heat flux through the wall. Results have been compared to the performance of a commercial insulating panel used as reference material: Batiboard expanded perlite. [8] This material has been selected for its wide use in building field as sustainable material with good fire resistance properties.
Three different specimens, with dimensions 180x180x45 mm, have been considered (Figure 1):
A_ Expanded Perlite
B_40% Cellulose fiber, 40% Paraffine PX28HC, 15% Borate Salts, 5% Basoplast Basf
C_40% Cellulose fiber, 40% Paraffine DS600, 15% Borate Salts, 5% Basoplast Basf

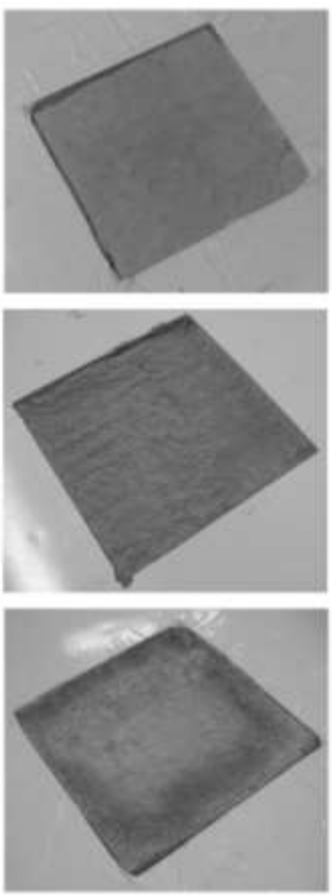
A
B
C

Figure 1: Material samples.

EXPERIMENTAL PROCESS
In order to perform thermal tests, simulations of summer temperature variations have been realized with reference to real data. Temperature values of August 2012 in three specific Italian cities (Milano in northern Italy, Palermo and Catania in southern Italy) have been collected. [9 - 10] The averages of temperatures are represented in Figure 2.

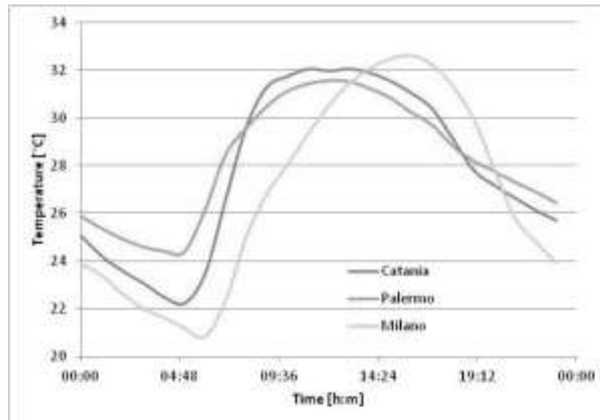

Figure 2: Averages of temperatures in August 2012.

Similar temperature conditions have been simulated with a heat source created using a light bulb inside a climatic chambre. Specimens were placed as insulating layer on the opposite wall as represented in Figure 3. Thermal sensors were placed in strategic positions in order to track the temperature variations inside and outside the chamber. Heat flux plate was placed on the external surface of each specimen in order to record the amount of thermal energy which passes through the material.
In this way, it has been possible to obtain a comparison between insulation performances of each panel and to estimate the benefit conferred by PCMs in terms of thermal maintenance.

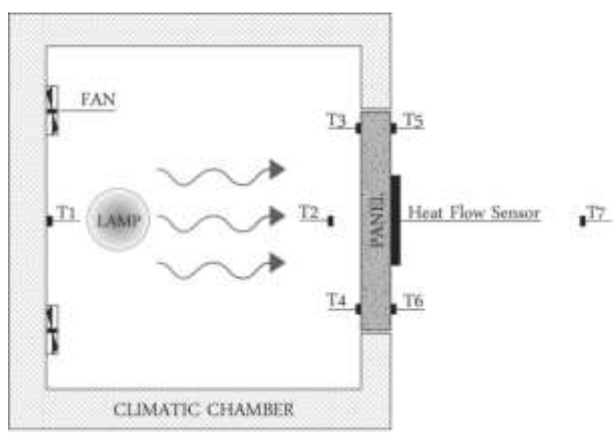

Figure 3: Climatic chamber scheme.

Once the lamp has been switched on, the temperature inside the chamber is raised from 20°C to 35°C. The time of temperature raising depends on the lamp power: it takes about 4 hours with a 22W bulb; it takes about 1 hour with a 25W bulb (Figure 4).

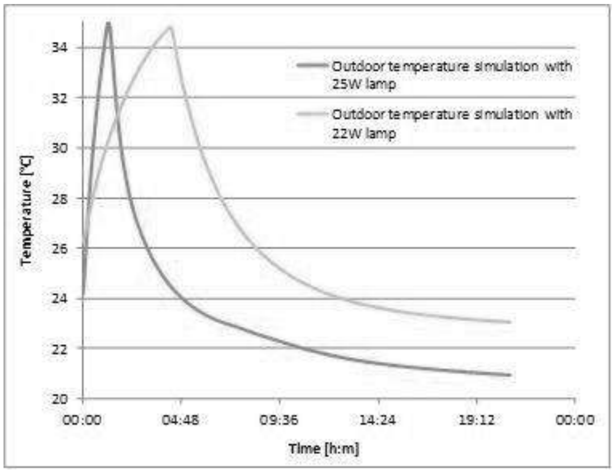

Figure 4: Temperature simulation inside climatic chamber.

As a result, using this system, variations of thermal flows during 24 hours of tests have been recorded for the three types of specimens. Area below each curve has been calculated as indication of the energy loss amount in a specific time.

RESULTS

First tests have been conducted using a 25W lamp. In Figure 5, thermal flows and areas variations under the thermal flows curves are represented.

It is possible to notice that Cellulose-PCMs panel with phase transition at 28°C has the better performance up to 12:30 hours of thermal test. After that time Perlite panel acquires better performance thanks to its lower thermal conductivity. Cellulose-PCM panel with phase transition at 26°C gives a good insulation till 3:30 hours of thermal tests when its thermal flows becomes higher than the ones of Perlite panel.

Second tests have been conducted with a 22W lamp. In Figure 6 thermal flows and areas variations under the thermal flows curves are represented.

It is possible to notice that PCMs with temperature transition at 28°C demonstrates better insulation performance than PCMs characterized by temperature transition at 26°C. After 4 hours of tests, when the lamp has been switched off and the temperature inside the chamber started to decrease, the gap between the two curves becomes higher.

Differently from the first tests, in this second case Perlite panel presents the best performance. Their thermal flow remains lower than those of Cellulose-PCMs panel with phase transition at 28°C. The gap between the two curves becomes smaller as the temperature reaches the transition value. When temperature becomes lower than 26°C the phase change phenomenon ends and the gap between the two curves increases again.

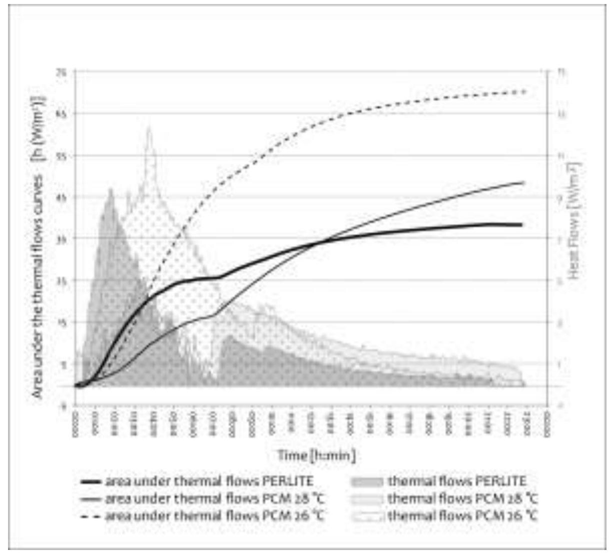

Figure 5: Heat flows and area variations during thermal test with 25W lamp.

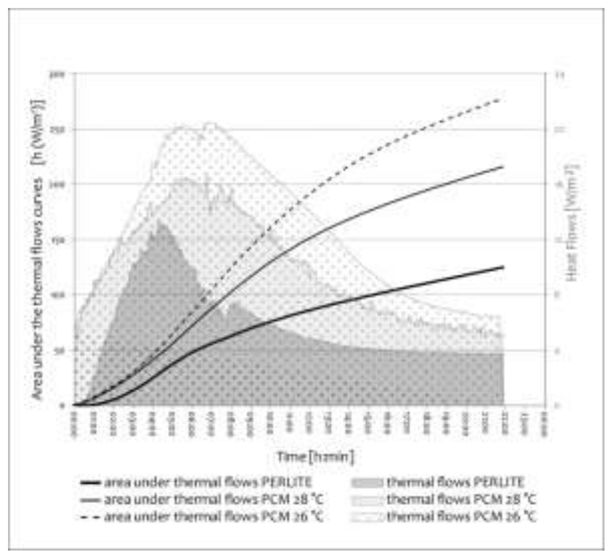

Figure 6: Heat flows and area variations during thermal test with 22W lamp.

CONCLUSION

The experiments conducted allow to figure out several conclusions.

The first one is the validation of the insulating functionality of the new panels developed. Thermal flows of PCMs panels B and C during the first thermal test resulted comparable to those of perlite panel A. In particular, during the increase of temperature, the insulating performances of all the three panels show

similar operation. When the temperature starts to decrease, there is a different thermal maintenance due to materials latent heat and thermal conductivity properties.
Results of the second test have suggested to work on a different structure for the PCMs panels. Works in progress are focused on the development of a foamed panel in order to evaluate the performance of a lighter material, which exploits the air insulating properties in addition to high heat accumulation properties of PCMs. [5]
A further conclusion is linked to the selection of PCMs: Paraffine PX28HC with phase transition at 28°C has shown better results than Paraffine DS600 with phase transition at 26°C.
The work done allows to use many data for the LCA analysis, which is in progress for a complete evaluation for future research. In particular, the amount of heat which flows through the panel during the test will allow to evaluate the difference in thermal performance between the materials and also gives an indication to define the functional unit for the LCA analysis. The amount of material necessary for the required thermal maintenance will affect the product sustainability in terms of resources consumption during the production phase, while the amount of thermal flows which passes through the same volume of material will affect the energy consumption during the working phase.
Moreover, the improvement of panels' thermal conductivity would be useful to maintain the high insulation performance achieved with PCMs also during temperature decreasing.
After the material characterization it will be possible to proceed a Life Cycle Assessment (ISO 14040-44) to verify the environmental performance of the composite material. As stated in the recent European Commission Recommendation of 9 April 2013 (2013/179/UE), measurement and information on the environmental performance of materials, products and services must comply with the life cycle method.
It means that instead of estimating the material impact, it would be more appropriate to estimate the effect that this new material confers to the life cycle of the product in which it is used.
In addition to assessing the environmental impacts of the material, Life Cycle Assessment examines the potential benefits arising from the application of this material in the use phase of the building (during indoor heating and cooling).
Actions expended for the reduction of environmental impacts in buildings (Directive 2010/31/EU) impose a near zero operating energy consumption on new buildings.
As highlighted by recent researches [11], to focus exclusively on the assessment of energy consumption in the use phase involves the shift of environmental impacts to the other phases, with a prevalence on building materials. For this reason the application of a building envelope made of secondary raw materials as recycled cardboard should not represent a risk, because it ensure low environmental impact even in the early stages of pre-production and production. These qualitative evaluation on the potential benefits of reducing the impact in the early stages of pre-production, production and use will be verified and quantified with the Life Cycle Assessment.

ACKNOWLEDGEMENTS

Authors gratefully acknowledge support from "Piz S.r.l.", "Ghelfi Ondulati S.p.A" and Regione Lombardia for the project "Naturalmente".

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