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Energy refurbishment of existing buildings through the use of phase change materials: Energy savings and indoor comfort in the cooling season

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HIGHLIGHTS

- Building envelope refurbishment by means of PCM plaster has been investigated.
- The analyzes vary melting temperature, thickness and location of PCM plasters.
- The reduction of cooling need is evaluated for five Mediterranean climates.
- Masonry-insulated buildings have been studied in realistic operating conditions.
- Guidelines are proposed for optimizing energy savings by means of proper PCM.

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ABSTRACT

With reference to building applications, recent scientific literature shows good potential in reducing cooling loads by means of phase change materials (PCMs), integrated in the building exterior envelope.

This paper proposes a deepening, by investigating if these dynamic components could contribute in reducing building cooling demand in Mediterranean climates. An office building is analyzed, with reference to the entire cooling season (from May 1st to September 30th), in reliable conditions as regards building use, and thus internal gains, occupancy, activation of cooling systems.

More in detail, through hourly energy simulation, the achievable cooling energy savings have been calculated, with reference to a well-insulated massive building, refurbished by means of addition of PCM plaster on the inner side of the exterior envelope. Five Mediterranean climates have been taken into account: Ankara (Turkey), Athens (Greece), Naples (Italy), Marseille (France), Seville (Spain). The studies regarded the influences of the phase change temperature, thickness of the PCM wallboard and location of the PCM layer.

Beyond the evaluation of the absolute savings of primary energy requests for cooling, the energy saving rate and the not-overheating time have been calculated, respectively by considering an air conditioned building and a naturally ventilated building with free-running indoor temperatures.

Starting from the achieved results, through the values of the proposed indicators, this paper would suggest information useful for proper design and selection of phase change materials for building applications.

1. Introduction

According to the communication of European Commission "A Roadmap for moving to a competitive low carbon economy in 2050", EU countries should reduce their emissions around 80%, within the 2050 and compared to the 1990 level, in order to go towards a competitive low-carbon economy and a sustainable future development.

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Nomenclature

EP_{COOL}	primary energy demand for the space cooling (kW h)
A	total surface area (m^2)
C_p	specific heat (J/kg K)
EER	energy efficiency ratio of chiller ($W_{THERMAL}/W_{ELECTRIC}$)
h	specific entalpy (kJ/kg)
L	thermal load (W)
t	time (h)
T	temperature (°C)
U	thermal transmittance (W/m^2 K)
x	thickness (cm)
DSC	differential scanning calorimeter
HFMA	heat flow meter apparatus
PPD	predicted percentage of dissatisfied (%)
Greek letters	
Δ	difference
λ	thermal conductivity (W/m K)
ξ	energy saving rate (%)
ρ	density (kg/m^3)
Subscripts	
i	modeled node
$i+1$	adjacent node to interior of construction
$i-1$	adjacent node to exterior of construction
int	internal
lig	lighting systems
j	current time step
$j+1$	new time step
pcm	referred to building with installation of PCM wallboard
Noh	not overheating
w	interface between i and i + 1 node

Thanks to a full implementation of current policies (i.e., increase of 20% of renewable sources and improvement around 20% in energy efficiency by 2020), the Europe could overcome the current 20% reduction target of polluting emissions. In this regard, the built environment provides low-cost and short-term opportunities. Indeed, the EU Commission's analysis shows that emissions, with reference to this sector, can be reduced around 90% within 2050 [1].

During 2011, Europe and Eurasia demanded energy for about 2923 million of tons of oil equivalent: this is almost 24% of the world's total energy use. With reference to the Euro-Area (27 countries), residential and commercial buildings required around 40% of the overall energy use [2].

According to the present EU policies, in the next years new buildings should be designed as low- or zero-energy buildings [3]. At the same time, energy-oriented refurbishments of the existing building stock are strongly recommended.

The demand-side management is an effective key for reducing the energy use, above all with reference to the energy required at the peak times. In this regard, the use of thermally enhanced building envelope components – for instance by incorporating phase change materials into traditional walls – can attenuate the heat transmission, shifting the time of the peak and reducing the peak load itself. This strategy is already supported by the Italian national legislation and could produce, above all for buildings characterized by a diurnal use, relevant margins in reduction of the cooling energy demanded for air-conditioning.

As known, energy can be stored in materials, by producing a change of internal energy, in form of sensible heat, latent heat and because of thermo-chemical reactions.

In the first case, the amount of stored heat depends by mass and specific heat of material, and the phenomenon induces a temperature variation. Diversely, accumulation of latent heat is based on absorption/release of energy during the change of state, from solid to liquid or from liquid to gas, or vice versa. The latent heat storage – by incorporating phase change materials (PCM) into envelope structures – presently is an attractive strategy, suitable for increasing the building thermal inertia, and thus proper for allowing time lag of the indoor temperatures' peak, by reducing also the amplitude of heat wave [4].

With the aim to increase the storing capacity of buildings, above all with reference to light-weight structures, several possibilities have been investigated during the last years. Most of these studies, in the following rows described, shows opportunities for shifting and attenuating the heat transfer between buildings and outdoor environment during both winter and summer seasons. Generally, the analyzes refer to few days.

This paper, beyond a large literature review, proposes a deepening about the effects of phase change materials integrated in the building envelope, with reference to a typical massive and insulated building, quite typical in the European cities. In particular, several studies have been carried out for various Mediterranean climates.

The main target is the quantification of the achievable energy savings, with reference to the entire cooling season, aimed to verify the potential of these materials for refurbishing common buildings and not only light-weight architectures. The heat transmission phenomena will be simulated by using a quite accredited building simulation program – EnergyPlus 7.2.0 – by recurring to the use of "one-dimensional conduction finite difference" as heat balance algorithm.

2. Phase change materials in building applications: state of art and motivations

The use of PCMs in building applications has been discussed in several papers, especially in order to investigate the effect on the human thermal comfort and for evaluating the variation of temperature fluctuations of the envelope surfaces [5–17]. Singularly, Table 1 infers aims, scope and results of the present state of art according to the scientific literature.

According to the present studies, the improvement of thermal comfort - allowed by the use of PCMs – is quite clear. On the other hand, few data are available about the amount of annual energy savings for the space heating and cooling, under realistic conditions of building use.

In this regard, this paper is aimed to evidence – according to various boundary conditions concerning installation, climates and thermal parameters of PCM – the achievable energy savings. Indeed, this research could be useful for the future development of PCM technology, in particular in order to support the design of proper PCM materials for building applications in Mediterranean climates. The main target is the identification of the most suitable PCM, with reference to the melting temperature and latent heat storage capability.

Starting from the one-dimensional non-linear mathematical model for heat conduction, and according to the effective heat capacity method, [18] investigates the influence of a new PCM wallboard applied to the inner building envelope. The authors