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# Energy assessment of a PCM–embedded plaster: embodied energy versus operational energy

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**Abstract**

Phase change materials (PCMs) are an emerging technology that can be integrated in building envelope components. PCMs are able to stabilise indoor air temperature and increase thermal energy storage especially in lightweight constructions. Within a research activity aimed at developing advanced plasters with improved thermal properties, a plaster which incorporates a microencapsulated paraffin-based PCM was developed. The paper highlights the importance of an overall analysis, facing both operational and embodied energy, since the expected decrease of the energy consumption during the operational stage difficultly counterbalances the high energy impact related to manufacturing processes.
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*Keywords:* Phase Change Material; plaster; embodied energy; operational energy

## 1. Introduction

In the latest years, many researches on advanced materials suitable for application in building envelope components have been carried out. Phase change materials (PCMs) are an emerging technology that can be integrated in building envelope components for new constructions as well as for refurbishment. PCMs are capable of stabilising indoor air temperature and increase thermal energy storage especially in lightweight constructions.

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For brevity, only the results of the energy need for heating and cooling for the cases of one and three non-adiabatic surfaces are reported in Fig. 1. Even though different PCM-embedded products are analysed, these results are not as promising as those reported in [7]. In the present study, the effect of the PCM in the reduction of the energy need for heating and cooling was not very significant due to the low PCM concentration and, consequently, to the low latent heat of fusion of the PCM plaster.

The greatest energy reduction was achieved with the use of the PCM_005-V2 plaster, whose PCM melting temperature of 23 °C lies within the free running range.

The advantages in the use of PCM-embedded plasters would be far greater if the thermal comfort during summer could be guaranteed without the need for a cooling system. For this to be possible, a higher PCM concentration together with the adoption of passive cooling criteria would be advisable in terms of operational energy. However, this target may not be achievable in all the climates.

### 4.2. Embodied energy

The environmental impacts were evaluated with the Life Cycle Assessment methodology defined by the UNI EN ISO 14040/44 [8]. The life cycle analysis was aimed at developing and improve a range of experimental prototypes of plaster with PCM and to evaluate the effectiveness of the PCM embedded in the plaster in relation to embodied energy and operational energy. The LCA method was developed in three progressive steps. The first one was the analysis of the raw material in order to support the design phase, the second step was the comparison between the prototypes and the Base plaster (benchmark), and the third one was the evaluation of the Embodied Energy in comparison with the Operational Energy obtained by means of numerical simulation for a case study. The Functional Unit for the former two steps was kWh/kg, while the Functional Unit of the last analysis was kWh/$m^2$ related to the net floor area of the simulated case study.

The system boundary – covering cradle-to-gate – included all the processes from the extraction of raw materials, transports, up to the plant processes of manufacturing and packaging. The Life Cycle Inventory was based both on indirect and direct data. The indirect data of the raw materials (natural hydraulic lime, gypsum plaster, calcium carbonate, flakes and additives) were retrieved from the database Eco-Invent v.2.0. The inability to retrieve direct data for the production processes determined the choice to study the PCM through the analysis of its two component materials, i.e. paraffin and polymethyl methacrylate. The scientific literature data on the encapsulated PCM was adopted; 60 wt. % of paraffin and 40 wt. % of polymethyl methacrylate are reported in [9]. The data on transport route and plant processes related to the manufacturing of the experimental thermal plasters were gathered directly from the companies involved in the research project.

Results of the LCA analyses of plasters are shown in Fig. 2 where the non-renewable and renewable energies were evaluated with the CED method v. 1.06. The comparison between 1 kg of plaster's raw materials, based on adaptation of data from Ecoinvent, highlights the high environmental impact of phase change materials in relation to the binders and other aggregates (Fig. 2).

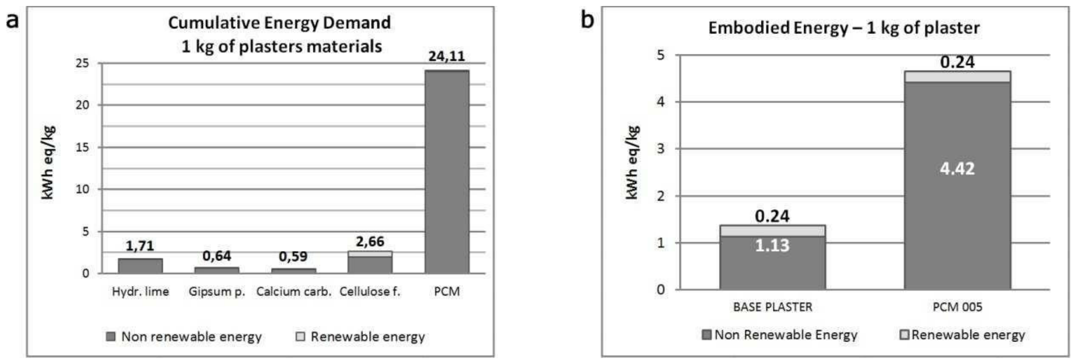
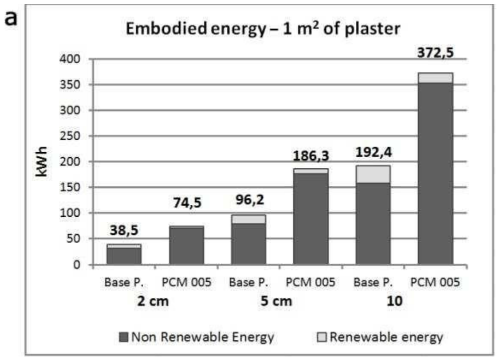



Fig. 2. Cumulative Energy demand of (a) plasters materials; (b) Base and PCM plasters.



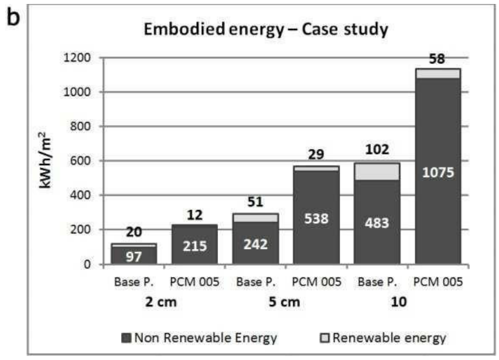




Fig. 3. Embodied Energy in: a) 1 m$^2$ of plaster; b) all plastered surfaces of the simulated room normalized on the net floor area.

The environmental and energy analyses on the material emphasise the high environmental cost of PCMs. The highest the amount of PCM, the highest the embodied energy that needs to be properly counterbalanced by the energy demand reduction in the operational phase (Fig 2.a). The analysis carried out on the thermal plasters highlights also a ratio of 1:4 on the cumulative energy demand of the Base plaster with respect to the PCM_005 plaster (Fig. 2.b). These results are in accordance with the embodied energy data reported in the Inventory of Carbon & Energy (ICE) realised by SERT of Bath University and in previous studies on plasters[10, 11].

To compare the embodied energy of construction powder products, the study of the consumption of product per surface unit in the installation phase is fundamental. The bulk density of materials in the blend and the concentration of aggregates affect the final weight of powder used per square meter. The amount of powder consumption per square meter can vary between 2.5 and 15-16 kg depending on the plaster characteristics. In this research, PCM_005 had a consumption of 8 kg per m$^2$ per cm of thickness, which is much lower than the basic plaster (14 kg per m$^2$ per cm of thickness). The differences between Base plaster and PCM_005 are quite evident (Fig. 3), but could be greater if a higher concentration of PCM product was used during plaster preparation. The embodied energy in the application of three thicknesses of PCM plaster (2 cm, 5 cm, 10 cm) on one square meter of wall highlights the big differences between Base and PCM plasters. In particular, the embodied energy in 5 cm of PCM plaster resulted very similar to that in 10 cm of Base plaster (Fig 3.a). To compare the embodied energy with the operational energy data, the embodied energy was calculated and normalised on the net floor area (25 m$^2$) of the simulated room, whose surfaces were all plastered with the exception of the floor. These results are shown in Fig 3.b.

## 5. Results and discussion

The comparison between embodied (EE) and operational energy (OE) for the investigated case study is shown in Fig. 4. Results were normalized on the net floor area of the simulated room and are reported in terms of yearly difference, over a period of 50 years, between PCM plasters and Base plaster with equal thickness. The value referred to total energy (ΔTE) resulting from the sum of yearly difference for both embodied and operational energies is also presented. The benefits in terms of operational energy for the analysed case study did not balance the high embodied energy content. From these results, the importance of analysing both EE and OE of PCM materials is highlighted. The adoption of PCM plasters could potentially be profitable when the highest reduction of OE can be achieved with the lowest amount of PCM. However, in the presented case study this condition was not met even using the PCM plaster only on the perimetral walls. A balance may be achieved in locations whose climate is similar throughout the year with a suitable optimisation of the PCM type, properties, quantity and position, and through a proper integration between building envelope and building services [12, 13]. In addition, an issue that would need further investigation is the durability of the PCM. The effect on the operational energy reduction resulting from alteration of the thermophysical properties of the PCM due to thermal cycling should be taken into account for properly evaluating the time frame of the analysis.

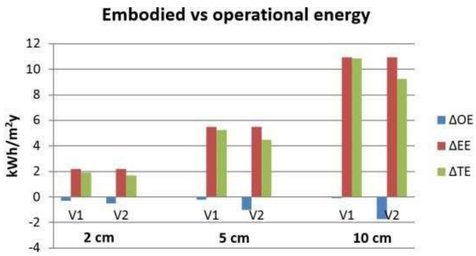



Fig. 4. Yearly difference of embodied energy (ΔEE), operational energy (ΔOE) and total energy (ΔTE) between the PCM plasters and the Base plaster with equal thickness, over a period of 50 years.

## 6. Conclusions

In the present work, a plaster which incorporates a microencapsulated paraffin-based PCM was developed. Laboratory measurements were performed on three plaster samples to assess their thermal conductivity and dynamic thermal behaviour in terms of time lag. In addition, an overall analysis of both operational and embodied energy was carried out. The operational energy was evaluated for a residential case study by means of numerical simulations.

Results addressed the importance of analysing both embodied and operational energy of PCM materials. For the analysed case study, the high embodied energy content of the PCM plaster was not counterbalanced by the benefits in terms of operational energy reduction. The effects of thermal cycling should be also taken into account.

In order for PCM plasters to become competitive materials from a global energy point of view, efforts should be made by the manufacturers to reduce their embodied energy.

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