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Theoretical and Practical Considerations for Using Phase Change Materials into Spanish Banking Office

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The service sector accounted for nearly 10 % of the total final energy consumption in Spain (414,692.157 GJ) in 2010, with the largest consumers being in the office sector and an increasing trend is expected in the coming years. Greenhouse gases (GHG) emitted by the commercial and institutional sector were the equivalent of approximately 8.2 Mt of CO_2. Consequently, energy savings in this sector offer the best means of reducing the energy demand.
Banking sector within the service sector have been studied in a previous research by authors where regression models for the prediction of the annual energy consumption in the Spanish banking sector were presented. Results provided relevant information on the energy performance of the Spanish banking sector and contribute new data for the energy performance of the sector. From this study, it was found that a balance between comfort and energy efficiency represents a great challenge. Within this scenario Phase Change Materials (PCMs) are willing to be studied and compared for obtain the above mentioned balance because they can passively cool and heat a living area without the need of including heavy mass or extra space typically required by sensible heat storage materials.
It has been demonstrated that for the development of a latent heat storage system (LHTS) in a building fabric, the choice of the PCM is key to improve the heat transfer mechanism in the building. They can be incorporated in the walls, ceiling and floor of buildings for further thermal energy storage and will help in reducing energy demands associated with temperature control. The potential for PCMs is great. For example, converting 0.45 kg of ice at 0 °C to 0.45 kg of water at 0 °C requires the "storage" of about 1.055 MJ, conversely, about 1,000 Btu are released as the water freezes. A temperature change of 5/9°C requires about 1.42 m^3 (3,175.75 kg) of concrete to store 1.055 MJ. The reduction in mass and volume offered by PCM use is potentially enormous.
To this end, this research develops an analysis to show environmental considerations regarding two PCMs that can be used into Spanish banking offices which have energy consumption behaviour different to residential sector. The analysis takes into account Spanish climatic severities and proposes essential strategies for planning and promoting different methods to decrease its environmental impact, to lower the consumption of energy resources, and to reduce economic costs.

1. Introduction

The building industry involves about 20-40 % of energy consumption worldwide (International Energy Agency (IEA), 2010). According to the Public Bank of Environmental Indicators of the Spanish Ministry of Environment (Public Bank of Environmental Indicators, 2008), the energy consumption in the Spanish building sector in 2008 reached 18,123 ktep which corresponds to 1.12 tep/home compared to

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1.7 tep/home in the European Union. This figure represents 17 % of the national energy consumption and accounts for 19438.9 kt of associated CO_2. On the other hand, the service sector accounted for nearly 10% of the total final energy consumption in Spain (408,799.152 GJ) in 2007 (IDAE, 2009), with the largest consumers being in the office sector, and an increasing trend is expected in the coming years. Greenhouse gases (GHG) emitted by the commercial and institutional sector were the equivalent of approximately 8.2 Mt of CO_2 (European Commission, 2010).
In addition, the Spanish energy use in buildings is increasing at a rate of 4.2 % per annum due to the increment in the number of heating, ventilating and air conditioning (HVAC) systems, among other reasons such as the economic growth and the expansion in the building sector. Actually, although much energy is directly consumed by the building design and construction stages, HVAC systems achieve ratios of about 20 % of the total energy use in buildings (Pérez-Lombard et al., 2008). This ratio increases dramatically when only the use stage is considered in the building life cycle because almost half of the energy consumption is linked to HVAC systems (Spanish Institute for Energy Diversification and Saving of Energy (IDAE) and European Comission (Eurostat), 2011).
In spite of significant trends and interest of the research community in the energy performance improvement of the service sector, there is a lack of information regarding the specific service sectors that have dedicated research efforts to study their energy consumption in more detail (Chen et al., 2008, Ward et al., 2008, Becken et al., 2001, Lam et al., 2010, Salem Szklo et al., 2004, O.A, 1991, Jaber and Probert, 2002, Mairet and Decellas, 2009).
This situation requires particular attention in order to achieve improvements in energy efficiency and savings in buildings during the use stage. In this sense, the thermal storage approach plays an important role, especially focusing on the incorporation of latent heat storage systems (LHTS) by introducing Phase Change Materials (PCMs) into construction structures (Pasupathy et al., 2008).
PCMs can passively cool and heat a living area without including heavy mass or the extra space typically required by sensible heat storage systems (Zhang et al., 2007). As an example, about 1.502 MJ are exchanged to convert 4.5 kg of ice at 0 °C to 4.5 kg of water at 0 °C. However, exchanging the same quantity of energy, varying the temperature 5/9 °C will require about 3,175.75 kg of concrete. The reduction in mass and volume offered by PCMs is notably large. Consequently, they can be incorporated directly into the walls, ceiling and floor of buildings for further thermal energy storage and will help reduce the energy demands associated with temperature control. However, their correct selection and application depend of the energy consumption performance. In a previous research, authors developed a regression model that predicts the energy consumption without widespread analysis and determines how efficient or inefficient in terms of energy a bank branch is, depending on its construction characteristics, climatic area and energy performance (Aranda et al., 2012). In this research, this mathematical model is used for analysing the use of PCMs into Spanish banking sector, from an environmental point of view. To this end, tiles modified with PCM are considered for managing the temperature within the comfort range (21-24 °C) in commercial offices. This leads to a significant increase in comfort for the users and a reduction in the HVAC load.

2. Methodology

As previously mentioned, a multiple linear regression model published by Aranda et al. (2012) was used for predicting the energy consumption by the banking sector in Spain. This model was carried out by analysing 4,732 random bank branches which were distributed across Spain and its 12 climatic areas according to the input data requirements for the regression analysis. The bank branches were represented in terms of climate area, number of inhabitants in the branch location and the annual energy consumption (it covers a range between 16,000 and 60,000 kWh/y, which corresponds with the value interval that characterise the total population being studied). For the analysis, a two-phase audit was carried out during 2010 and 2011 according to the following steps: a) preliminary data gathered by questionnaire sent via email to the company responsible for the maintenance and b) an on-site walkthrough audit with data gathering and measurement.
To gain new knowledge, this research develops an environmental analysis based on the Life Cycle Assessment (LCA) methodology to determine if energy savings are large enough to balance the environmental impact originated during PCM manufacture. Inputs and outputs of each management

stage have been defined and the inventory emissions calculated using SIMAPRO v 7.3.2 (PRé, 2007) and the Ecoinvent v 2.2 database (Ecoinvent Centre, 2007).

To incorporate the PCMs into the banking office, tiles modified with PCM are considered as the route for managing the temperature within the comfort range (21-24 °C) in banking offices. The PCM added to construction materials can be based on organic (paraffin, fatty acids and the polyethylene glycol) or inorganic (salt hydrates) compounds. In comparison to inorganic PCMs, the organic compounds show congruent phase changes, they are not dangerous because of their chemical stability, they can be recyclable and they have a good nucleation rate.

On the other hand, although salt hydrates present high volume change and supercooling and segregation phenomena, their main advantages are the high volumetric LHTS capacity, high thermal conductivity and the sharp phase change (Kuznik et al., 2011).

In this research two PCMs with operating temperatures included in the comfort range were analysed, an organic paraffin based material (PCM1 - Micronal DS5008X, Basf) (BASF - The Chemical Company, 2011) and one sodium sulphate, water and additives compound (PCM2 - ClimSel C24, Climator) (Climator, 2011). Table 1 presents the main thermal properties of these PCMs where T_f is the temperature of fusion, H_f is the latent heat of fusion. In all cases, the PCM layer is fixed to the tile by means of a resin.

Table 1. Main properties of the PCMs considered in the research study

Properties	Units	PCM 1	PCM 2
T_f	°C	23	24
H_f	kJ/kg	100	126

Considering the properties of each PCM, i, the overall heat storage capability can be determined by Eq 1. Eq 1 calculates the total energy exchanged due to the latent heat content available at T_f where n_i is number of phase changes that occur during a specific period time and mi is the mass of the PCM_i. The behaviour of a PCM with respect to the latent heat over time can be modelled by a modified step function as described in Figure 1.

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$$E_{latent,i} = n_i \cdot m_i \cdot H_{f,i} \qquad (1)$$

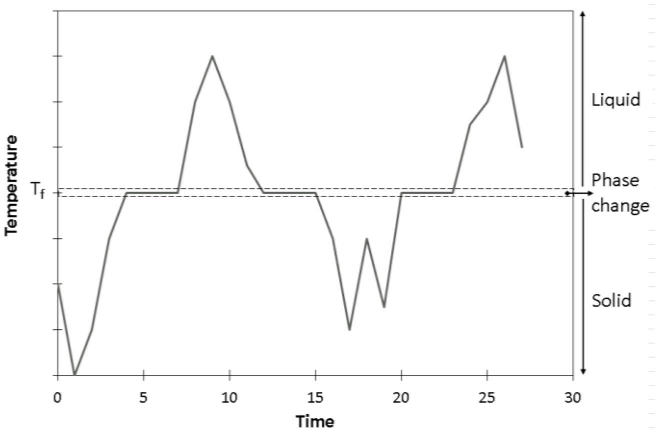

Figure 1: Graph showing the temperature behaviour during the phase change

The most up-to-date structure of the LCA is proposed by the standard ISO 14040 (International Organization for Standardization, 2006). This methodology is synthesised in four interrelated phases between them: goal and scope definition, inventory analysis, impact evaluation and interpretation.

In this study, three Spanish target areas with different climate severities have been analysed. Taking into account the climate severities in Spain the following locations are defined: by A4 (Almeria), B3 (Valencia) and D3 (Zaragoza). The annual weather data associated for 2010 was acquired from the State Meteorological Agency of Spain (AEMET) (State Meteorological Agency of Spain (AEMET)). This source provided temperature data for the different target areas hourly. Considering the T_f for each PCM is possible to calculate the parameter n_i included in Eq 1.

2.1 Scope of the analysis and functional unit

The impact assessment was carried out with the purpose of evaluating the endpoint approach. To this end, the Recipe methodology with a time frame of 50 years was applied to evaluate it. Endpoints are those elements of an environmental mechanism that are in themselves of value to society e.g. damage to human health or to ecosystem diversity. The functional unit is a surface area of 4 m^2 that can be covered with the tile in a standard office. In addition, the electricity used considers the production mix corresponding to the Spanish energy production system.

On the other hand, the system studied covers from the tile manufacturing to the disposal stage of the components. Consistent with the goal of the assessment, this study focuses mainly on the addition of PCM to tiles used in building constructions and the effects this causes on the annual energy consumption (E_{cons}) for air conditioning during the lifetime of the building and the subsequent environmental impact on the global system. Consequently, the use phase is modified and new processes related to PCM manufacturing, installation in the tile or final PCM disposal appear. As a first approach, in this study the disposal stage considers the landfilling of the PCMs at the end of use phase. Taking into account that the rest of stages are common to both situations (one of them refers to tiles without PCMs and another to tiles with PCM), their contribution to the environmental impact is the same and, therefore, they can be disregarded when both situations are compared.

2.2 Life Cycle Inventory

Data has been obtained by the combination of different sources which allowed developing the LCI considering the functional unit established previously. Mainly two different data sources have been consulted: (i) Research studies (Oliver Ramírez, 2009, Cerón et al., 2011) and (ii) data provided through questionnaires by private sector sources who are involved in the development of new products with PCMs. Table 2 shows this data in the case studies under the system boundary considered maintaining a constant PCM load of 2.5 kg_{PCM}/m^2.

Table 2: Life Cycle Inventory for the system boundary analysis

Properties	Unit	Input
PCM1		
Paraffin	kg	10.00
Resin	kg	23.45
$E_{manufacturing,1}$	kWh	5.00
$E_{cons,1}$	kWh	Table 3
PCM_2		
Sodium sulphate	kg	4.44
Water	kg	5.66
Resin	kg	23.45
$E_{manufacturing,2}$	kWh	5.00
$E_{cons,2}$	kWh	Table 3

3. Results and discussion

Table 3 shows the theoretical energy consumption associated with the case studies involved in this research and the rate of energy saving achieved as a function of the PCM type and the climate severity. The results show predominant energy savings from 17.51 % up to values around 28.07 % with a strong dependence on the climatic severity analysed and the PCM used. These results show the high savings potential of these materials. Analysing the data obtained for each type of PCM, PCM_1 and

PCM_2 undergo the same number of phase changes when CS B3 is evaluated. In this case, the savings corresponding to PCM_2 are higher because the latent fusion heat is greater, which leads to an increase in energy storage per phase change implemented.
Owing to the energy results obtained, an extended analysis was carried out to determine environmental impacts associated with each scenario considered. Table 4 show the endpoint assessment calculated by the Recipe method. The greatest environmental benefits are obtained with the PCM_2 for all climate severities and all the environmental categories analysed where the greatest performance reached was that corresponding to case A4.

Table 3: Energy consumption for air conditioning in building samples and PCM types

cs	$E_{w/o,PCM}$ (MJ)	n_1	$E_{cons,1}$ (MJ)	$E_{saving,1}$ (%)	n_2	$E_{cons,2}$ (MJ)	$E_{saving,2}$ (%)
A4	1,059.51	229	829.51	21.71	235	762.15	28.07
B3	1,633.54	285	1,347.54	17.51	285	1273.18	22.06
D3	1,320.81	279	1,040.81	21.20	275	973.05	26.33

Table 4: Endpoint impact assessment results

Impact category	Unit	PCM free	PCM_1	PCM_2
Climate Severity (A4)				
Human Health	DALY	$7.31\cdot10^{-3}$	$5.84\cdot10^{-3}$	$5.36\cdot10^{-3}$
Ecosystems	species.y	$3.05\cdot10^{-5}$	$6.40\cdot10^{-5}$	$6.20\cdot10^{-5}$
Resources	$	$1.52\cdot10^{4}$	$1.23\cdot10^{4}$	$1.11\cdot10^{4}$
Climate Severity (B3)				
Human Health, SC	DALY	$1.13\cdot10^{-2}$	$9.41\cdot10^{-3}$	$8.89\cdot10^{-3}$
Ecosystems	species.y	$4.70\cdot10^{-5}$	$7.89\cdot10^{-5}$	$7.67\cdot10^{-5}$
Resources	$	$2.34\cdot10^{4}$	$1.97\cdot10^{4}$	$1.84\cdot10^{4}$
Climate Severity (D3)				
Human Health, SC	DALY	$9.12\cdot10^{-3}$	$7.29\cdot10^{-3}$	$6.81\cdot10^{-3}$
Ecosystems	species.y	$3.80\cdot10^{-5}$	$7.00\cdot10^{-5}$	$6.81\cdot10^{-5}$
Resources	$	$1.90\cdot10^{4}$	$1.53\cdot10^{4}$	$1.41\cdot10^{4}$

4. Conclusions

This research develops an analysis to show environmental considerations regarding two PCMs that can be used into Spanish banking offices which have energy consumption behaviour different to residential sector. The analysis takes into account Spanish climatic severities and proposes essential strategies for planning and promoting different methods to decrease its environmental impact and to lower the consumption of energy resources using passive thermal systems as are the PCM. The results demonstrate that greatest results are achieved by the use of the PCM 2 in a climate severity type A4. Nevertheless, benefits are obtained in all climate severities and both PCMs in comparison with the sceneries without them.

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