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New database on phase change materials for thermal energy storage in buildings to help PCM selection

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Abstract

According to the International Energy Agency (IEA) the primary energy production was increased by 49% and CO_2 emissions by 43% over the past 20 years. Furthermore, 30 - 40% of total energy consumption in developed countries comes from the private sector (housing and offices). Thermal energy storage (TES) is proposed as one way to improve the gap between energy consumption and energy supply. TES systems can store energy as sensible heat, latent heat or chemical reaction. Phase change materials (PCM) are extensively studied materials for thermal energy storage as latent heat because these materials have high phase change enthalpy in a wide variety of phase change temperature. Nowadays it is quite difficult to have all the reported information about PCM properties, not only the thermophysical ones but other relevant properties, even though there are different compilations. CES Selector is software used in material selection, besides being a materials database it permits to include new materials introducing their properties, as well as to classify them in several groups, to plot the data and combine graphs production with the material selection under the desired criteria. More than 300 substances used as PCM and reported in the literature were introduced in a new database created using CES Selector. Thermophysical properties as melting temperature (ºC) and melting enthalpy ($kJ \cdot kg^{-1}$) have been plotted and PCM selections under different criteria were carried out. This database can be completed in the future with other relevant properties either than thermal such as chemical properties (durability in different media etc), reported density or viscosity at a given temperature or even cost of each material. Analyzing these plots it is observed that some PCM are represented occupying a wide range of a given thermophysical property. This is the case of $CaCl_2 \cdot 6H_2O$: data came from 7 sources and the occupied area in the plot is the highest one from all the PCM reported. On the other hand, some other PCM are represented with smaller dots associated with a lower dispersion in the property values and this size may possibly be attributed to different reasons: scarce sources for experimental data or low dispersion among several experimental reported values. These results emphasize that there is a lack of standardization for the measurement of the PCM thermophysical properties.

Selection and/or peer-review under responsibility of ISES.
Key words: Thermal Energy Storage (TES), Phase change material (PCM), Selection of Materials, CES Selector

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1. Introduction

According to the International Energy Agency (IEA), the primary energy production has increased 49% and CO_2 emissions 43% over the past 20 years [1]. Furthermore, 30-40% of total energy consumption in developed countries comes from the private sector (housing and offices). In addition, in recent years and due to the rapid growth in number of world's population, households, floor building area, and developed area in our planet, electricity demand for electricity-consuming devices and new products increased intensely [2].

Thermal energy storage (TES) is proposed as one way to improve the gap between energy consumption and energy supply [3]. TES systems can store energy as sensible heat, latent heat or chemical reactions. This study is based on phase change materials (PCM) which were extensively studied materials for thermal energy storage as latent heat because these materials have high phase change enthalpy in a wide variety of phase change temperature.

Actually, there are different compilations to collect all the reported information about PCM properties, not only the thermophysical ones but also other relevant properties [4].

Cabeza et al. reported in 2011 [5] PCM for building applications (low/moderate temperature of fusion) available in the literature classified by temperature of melting point as well as commercial materials marketed as PCM. Data from these PCM collected by Cabeza et al. were introduced in this study in the CES Selector database [6]. CES Selector is a software used in material selection and permits to introduce properties of different materials, to classify them in several groups; to plot the data and combine graphs production with the material selection under the desired criteria.

Depending on melting temperature of PCM, these substances are classified by applications. Thermophysical properties as melting temperature (ºC) and melting enthalpy ($kJ \cdot kg^{-1}$) have been plotted and PCM selections based on several applications are carried out in this paper.

The main objective of this study is to create a database that facilitates the selection of the most suitable PCM depending on the application.

2. Methodology

Abhat et al. [7] classified the substances used for thermal energy storage (TES). This classification is shown in Figure 1.

There are several substances which can be used as PCM due to their high latent heat of phase change but some of them are difficult to get from the market because they are not commercialized. Furthermore, there are some mixture or eutectic mixtures that present noble thermophysical properties but researchers have to formulate and manufacture these mixtures at laboratories because most of them are not available commercially.

Nomenclature

TES	Thermal Energy Storage
PCM	Phase Change Materials
IEA	International Energy Agency
TCM	Thermochemical Materials

In this paper, more than 300 substances were introduced in a database taking in consideration the melting point and the latent heat of fusion. These substances were state as available substances or studied ones to be used as PCM by Cabeza et. al. [5] and they are considered PCM because satisfy some or all following PCM requirements:

- high value of the heat of fusion,
- high value of specific heat,
- a melting point which matches the application,
- chemical stability and non-corrosiveness,
- not be hazardous, highly inflammable or poisonous,
- a reproducible crystallization without degradation,
- a small subcooling degree,
- small volume variation during solidification,
- a high thermal conductivity, and
- availability and abundance.

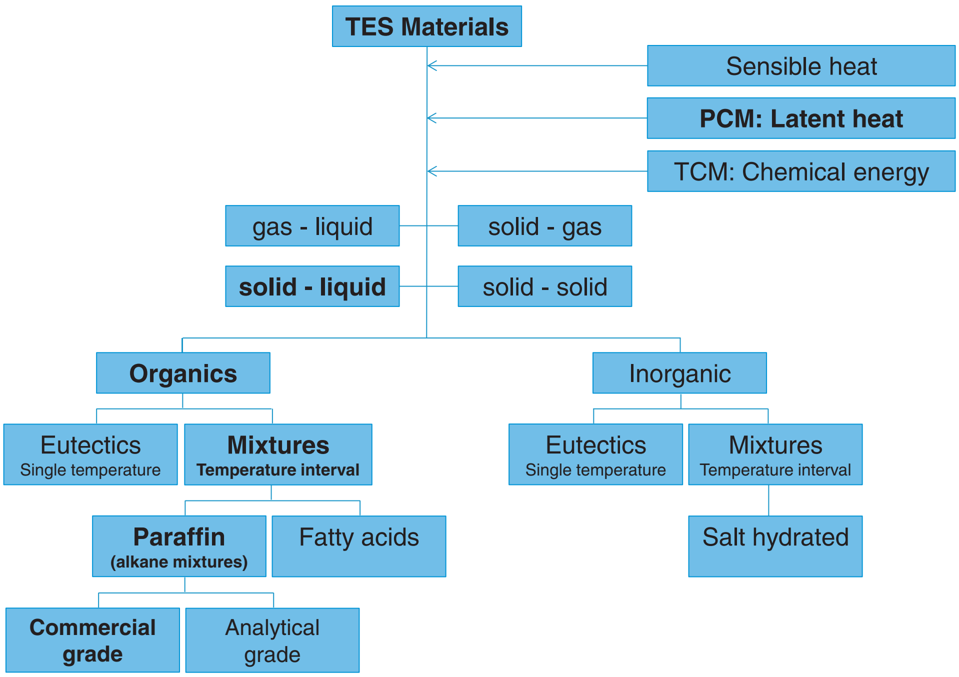

Fig. 1. Classification of energy storage materials [5,7]

Using the new database introduces in the software CES Selector; the PCM will be classified by applications. There will be 7 Figures containing this classification.

3. New database

In Figure 2 the first diagram with the first classification where all PCM can be used for building applications (active or passive systems) are plotted. Thereby, melting temperature vs. latent heat of fusion of all these substances is plotted and the different colors present different groups or nature of PCM: Eutectic, Organic, Fatty acid, Paraffin, Inorganic. Depending on the requirement of the system to implement the PCM, the selection of the substance with highest latent heat of fusion for a given melting point may be performed easily in the graph. Different bubble color means different building temperature range depending on the application. It can be observed that a wide range of values of latent heat is reported for a given application like cold storage, which includes ice as one of the materials with the highest latent heat.

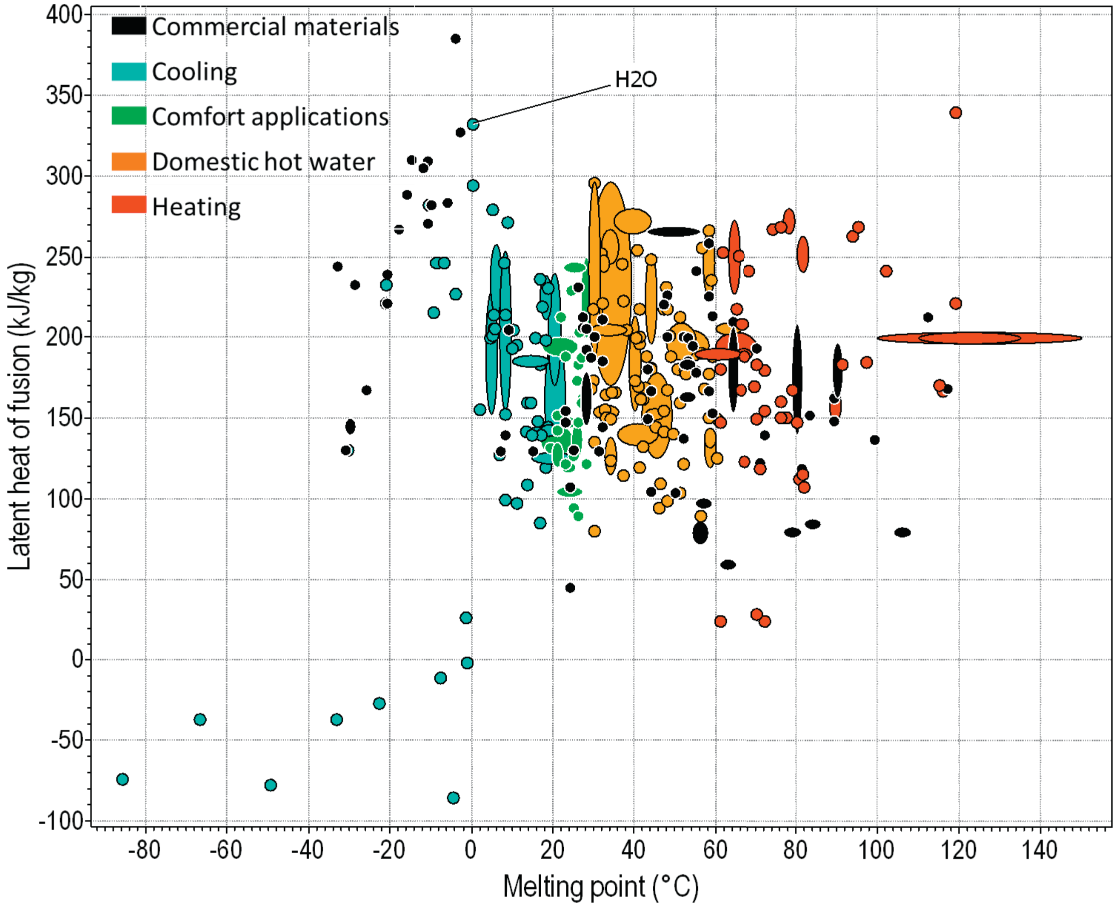

Fig. 2. PCM reported by Cabeza et. al. [5] concerning building applications using in active or passive systems

The aim of this paper is to present the use of this tool to select the best PCM for each application based on the data available in the literature and introduced in the CES Selector Software. For that reason, one figure for each application is presented in this section. Note that each figure considers different temperature range and then, the scale is not the same for all of them.

PCM are reported for cooling applications in buildings with melting temperatures up to 21 ºC. All substances available for this application (commercial and not commercial) are plotted in Figure 3. Different bubble color means different nature of PCM and most of them have a latent heat within the range 100-250 kJ/kg. It is interesting to note that shape and size of the bubbles is quite diverse. This may be due to several reasons: few or even single data reported for a given substance, or the opposite, a broad set of values for melting temperature and/or latent heat for a given substance.

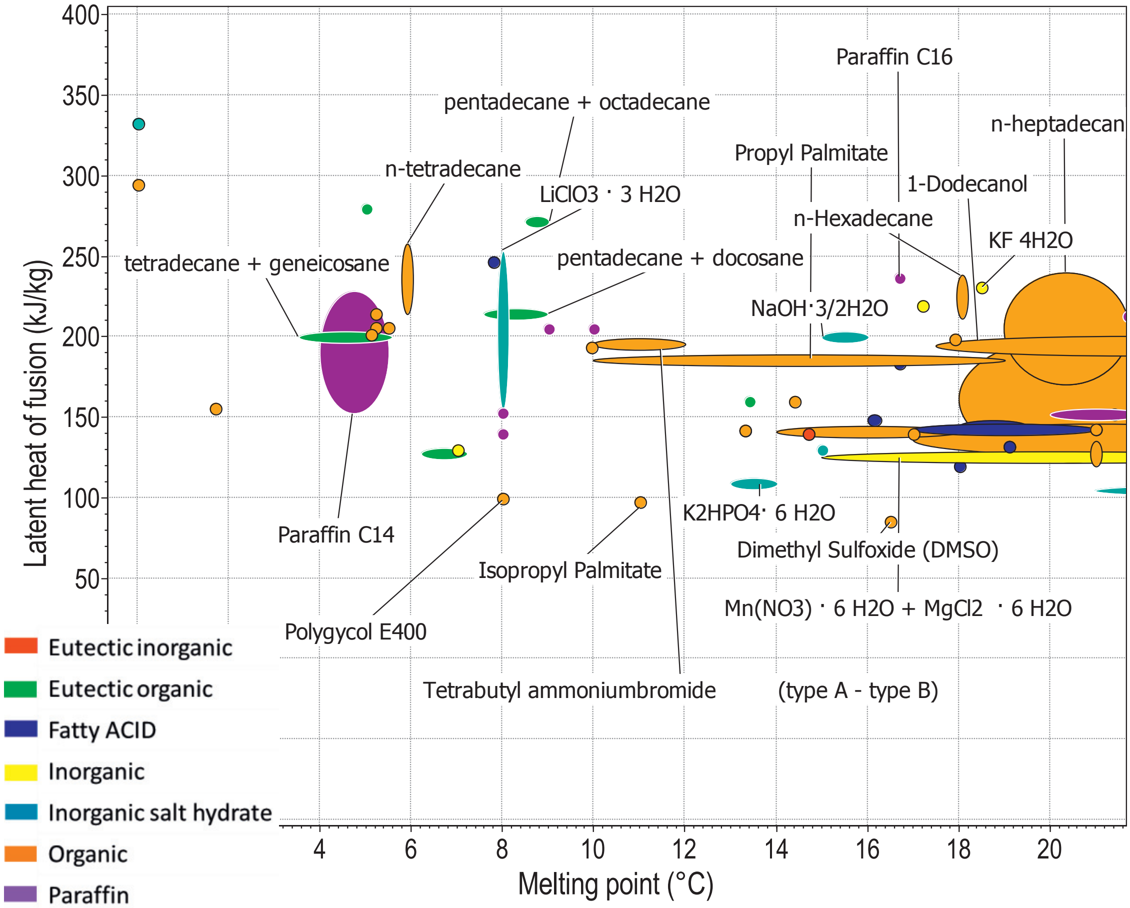

Fig. 3. Material classification of PCM used for cooling applications (melting temperature up to 21 ºC).

On the other hand, PCM reported to control the comfort temperature in indoor buildings are plotted in Figure 4. The temperature range selected was between 20 and 30 ºC and this PCM are commonly used in passive systems. This window can be larger or shorter depending on the climate conditions where the PCM system has to be implemented. Again, some of the PCM show narrow ranges of melting temperature

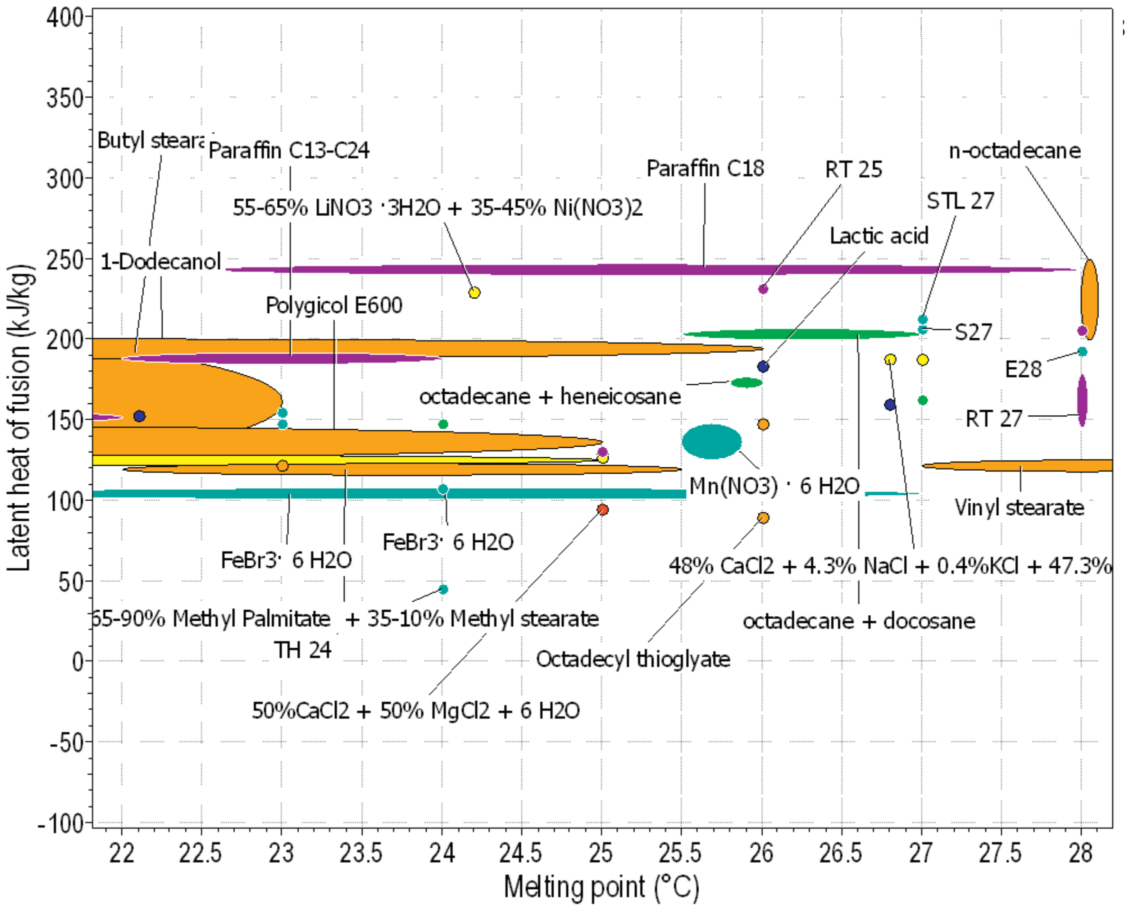

Fig. 4. Material classification of PCM used for comfort applications in buildings (between 20 and 30 ºC)

Furthermore, PCM used to store energy for domestic hot water application are plotted in Figure 5. The working temperature range considered was between 29 ºC and 60 ºC. This figure shows that for this application, there are many PCM from different nature and the working temperature will play an important role during the PCM selection because there is at least one PCM of each family plotted in Figure 5.

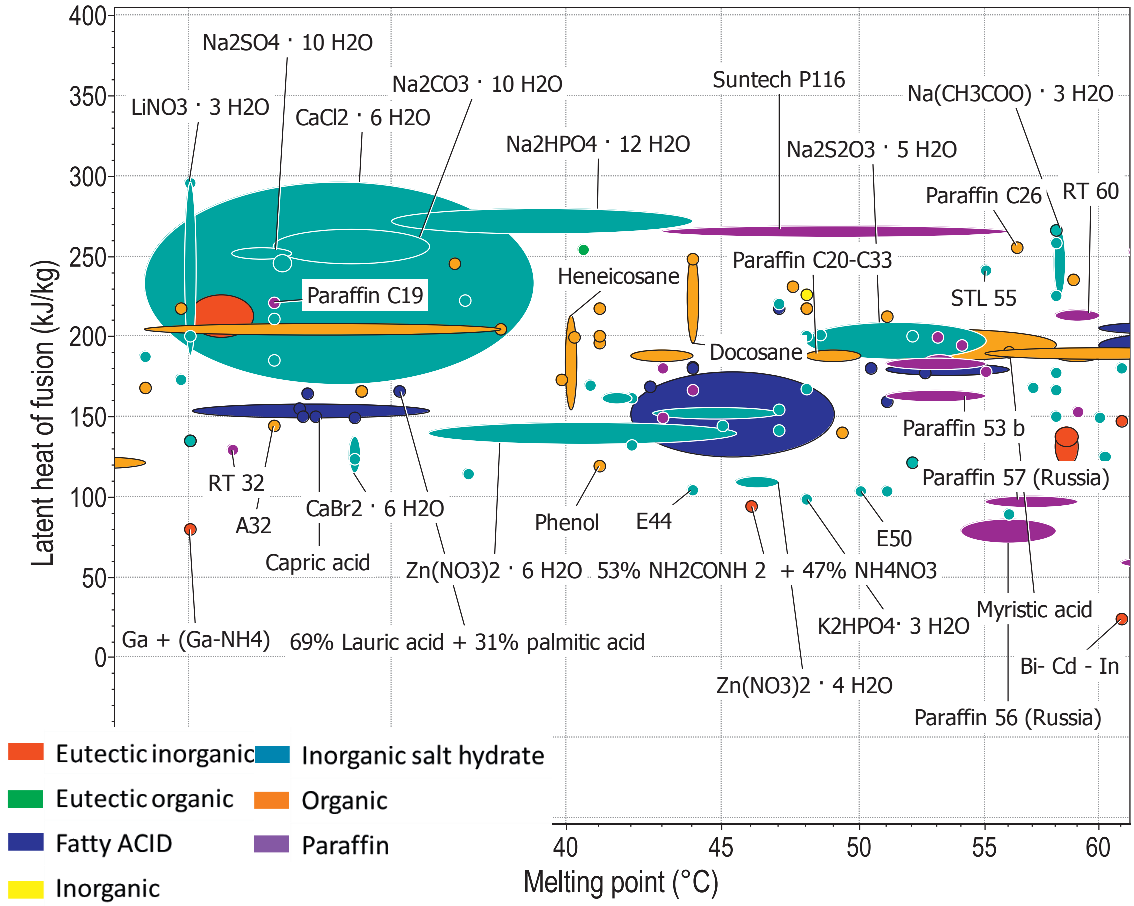

Fig. 5. Thermophysical properties of materials for hot water applications (between 29 and 60 ºC)

In addition, some other important information can be extracted from this way to present the different PCM available or studied:

- Large bubbles show that the thermophysical properties available in the literature are not completely consistent and, standardization about how to measure thermophysical properties of PCM will be a key point at short term [8].
- Some commercial materials can be related to a substance because both have same or similar thermophysical properties. This is the case of RT-27 / E28 / octadecane plotted in Figure 4. All these PCM have same melting temperature changing only the latent heat of fusion.

Furthermore, there are other applications as solar cooling, cold storage, etc. where PCM selection is a key point as well. Therefore, further incorporation of other PCM will be part of next step to perform with this software of Material Selection.

Moreover, there are some microencapsulated PCM available in the market, slurries, etc. which are not include yet in this database and their incorporation is needed. This step is important and will be considered for further research.

4. Conclusions

In this study is presented a new database to help during the selection process of PCM depending on the requirements of the application.

PCM are classified by working temperature of the application and nature / family of the PCM as well. Advantage and disadvantage of selecting a PCM will depend on the nature of the PCM. Because of this reason, this database is innovative and interesting.

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