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# THE BRAZILIAN PERSPECTIVE OF THERMAL ENERGY STORAGE FOCUSED ON AIR CONDITIONING AND WATER HEATING FOR BATH: LITERATURE REVIEW

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**Abstract.** *The production of cold during the night and the production of heat during the day favor technical and economic aspects. Added to this the search for the use of renewable energy in heat pumps and refrigeration equipment. Meantime, the operation in these conditions, in general, decouples the consumption schedule from the energy production schedule, thus demanding the use of storage systems. A comprehensive literature review with the object of study solutions for energy storage in air conditioning systems and heat pumps for heating bath water, will be displayed. The solutions will include storage in the form of sensitive and latent heat, considering particularly the phase change materials (PCM). The data will point operating range and applications in which the materials were used. Finally, these notes may guide technological development research as well as professionals working in these market segments and the types of materials that can be used in TES from the Brazilian perspective will be explored.*

**Keywords:** *thermal energy storage, heat pump, air conditioning, water heating, brazilian perspective*

## 1. INTRODUCTION

Currently, one of the main challenges facing society is the high consumption of energy and, consequently, the use of non-renewable energy sources, generating impacts on the environment. The search for new technologies to obtain greater energy efficiency, as well as reducing the need for it, is due to the growing concern with environmental issues, as well as the high cost of the energy generated (Agyenim et al., 2010). Energy consumption is expected to increase due to standard of living, in addition to population growth and climate change, requiring higher energy expenditure to maintain thermal comfort (Carvalho et al., 2019).

In the literature consulted, the term heat pumps can be used to describe either the equipment to product heating or cooling. In order to guarantee thermal comfort, it is necessary to act in the heating, ventilation, and air conditioning (HVAC) systems, since they are responsible for 21.4% of electricity consumption in Brazil (EPE 2019). On a worldwide scale, about a third of the energy used is destined for domestic use, in the European Union, for example, 70% of that energy is destined for heating/cooling water and environments (Lizana et al., 2018). The International Energy Agency (IEA) includes heat pumps for heating and cooling as one of the technologies with the greatest long-term potential to reduce CO<sub>2</sub> emissions. According to the proposed scenario by BLUE Map (a scenario in which energy-related CO<sub>2</sub> emissions are reduced by 50% in 2050 compared to 2007 levels), it is estimated that heat pumps will dramatically increase their share in air conditioning and water heating (International Energy Agency, 2011).

A possible solution for reduction of energy waste, is precisely its storage through thermal energy storage (TES) systems, where there is a difference between energy availability and consumption (Sharma et al., 2015; Monteiro, 2018). TES technology plays an important role in the field of air conditioners. During the summer, the use of this device

can represent up to 85% of the energy consumption by commercial and domestic buildings during peak hours. Energy storage under cooling is a way to bridge the gap between energy supply and demand, as cold energy storage technology in air conditioning is a way to save energy. This technology has been gaining worldwide attention and has been used in several applications, such as ice storage, food, transportation of materials sensitive to high temperatures, among others (Li et al., 2019).

Thermal energy storage systems can be classified as sensitive heat storage system, storing energy with the variation of the temperature of a material or as latent heat storage system, storing energy during the phase change of a material. It is essential that in both systems the materials that are used have properties which are matched with the type of mechanism used to store energy (Monteiro, 2018).

This paper aims to present a literature review considered works that combined heat pumps and TES. Then, it highlights the perspectives for Brazilian scenario, in particular, for the air conditioning and water heating systems. This information could be used as a reference in future studies and projects.

## 2. THERMAL ENERGY STORAGE

### 2.1 Heat pump and thermal energy storage

Figure 1 presents a generical heat pump system that is able to produce and storage heat and / or cold through a vapor compression cycle. The refrigerant flows through lines in black. When it passes in the evaporator it absorbs heat from the heat transfer fluid (HTF) shown in blue lines. Then, the cooled HTF could be used instantly in the Fan Coil or stored in Cold TES for future use. Additionally, when the refrigerant flows through the condenser it rejects heat from the HTF shown in red lines. After that, the heated HTF could be delivered for consume or stored in Hot TES for future use. As an example, water is used as the HTF in Figure 1.

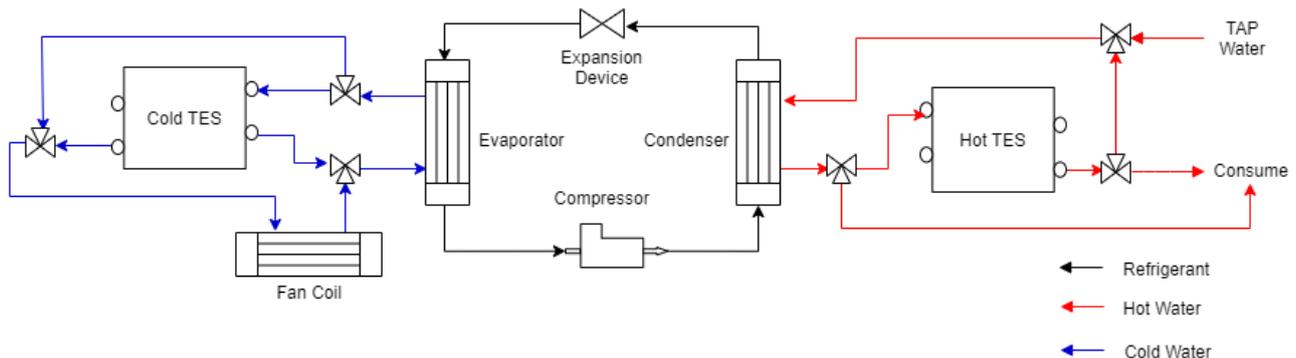


Figure 1. Flowchart integrated refrigeration system and TES for hot and cold water.

### 2.2 Phase change materials (PCMs)

Phase Change Materials (PCMs) are materials that have a large capacity to store energy in the form of latent heat. PCMs can store 3 to 4 times more heat per volume compared to sensitive heat storage systems (Monteiro, 2018). Therefore, PCMs are extensively used in TES systems.

Latent heat is the heat generated in a reversible phase change during which thermal energy is stored and it occurs when the ambient temperature varies. As the temperature increases, the chemical bonds of the PCM breaks, transforming its solid state to the liquid. In the same mechanism, when the temperature decreases, the PCM returns to the solid state releasing the previously absorbed and stored heat (De Carvalho, 2019).

PCMs have been tested over the years as a renewable energy solution that has aroused interest as an alternative or complement to equipment that consumes natural resources. The use of this type of material has already been studied in the most varied areas, such as textiles, food and construction. These materials work as a complement to the heating or cooling systems, so that they can reduce energy consumption and the costs associated with these (Teixeira, 2019).

Abhat (1983) suggested that the materials used for energy storage should be classified into two broad categories according to the type of heat used for this storage: sensitive heat and latent heat (De Carvalho, 2019). PCMs are classified within the group of materials that storage energy through latent heat and are further subdivided into two other broad groups: organic and inorganic. The subdivision proceeds with the classification of mixtures and eutectic mixtures, in addition to more restricted classifications. Figure 2 illustrates this classification.

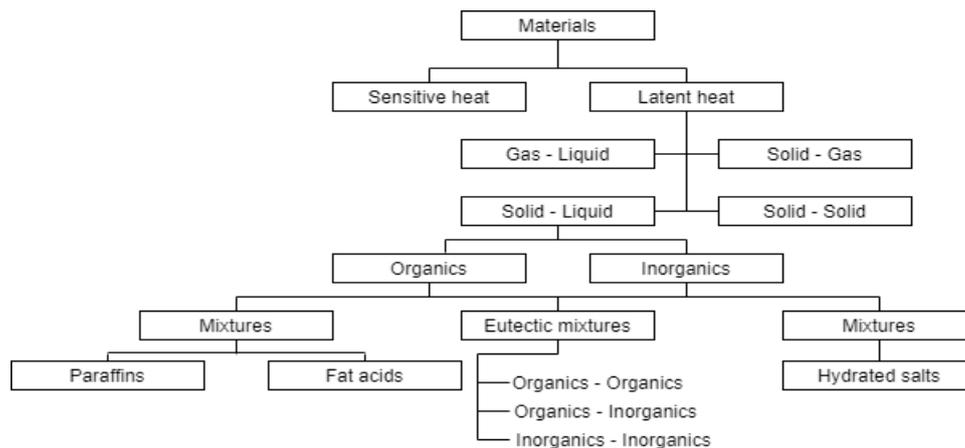


Figure 2 – PCMs Classifications (Sá, 2012)

The use of PCM is only possible if it meets certain thermal, physical and chemical characteristics, compatible with the system in which it will be used, as well as its conditions of use. It is also important that they are economically viable and easily accessible on the market (De Carvalho, 2019).

### 2.3 Thermal energy storage focused on air conditioning

In this paper, other studies were analyzed in which PCMs were used to store thermal energy for posterior use. For application in air conditioners, it is necessary that the chosen PCMs be able to store cold and transfer it when requested or programmed. In addition, the PCM’s melting point must be consistent with the purpose of changing the phase and the local where the experiment was carried out due to the average temperatures of each region.

Table 1 presents different studies related on thermal energy storage focused on air conditioning. It shows PCM type, PCM’s melting temperature, tank size, refrigerant, heat transfer fluid (HTF), coefficient of performance (COP), if the study is theoretical or experimental and location.

Table 1. Studies on thermal energy storage focused on air conditioning

Authors	PCM	PCM’s Melting Temperature (°C)	Tank Size (L)	Refrigerant	HTF	COP	Theoretical or Experimental Study	Location
Mettawee <i>et al.</i> (2012)	Coconut Oil	22-24	-	-	20 % ethylene glycol by volume and water	-	Experimental	Egypt
Al-Abidi <i>et al.</i> (2013)	RT82	77-85	-	-	Water	-	Experimental	-
Fals <i>et al.</i> (2014)	Water	0	-	-	R404A	1.685	Theoretical	-
Moreno <i>et al.</i> (2014)	S10	10	104	-	Water	-	Experimental	Lleida (Spain)
Chaiyat (2015)	RT20	20–22	-	R134a	-	-	Experimental	Thailand
Osterman <i>et al.</i> (2015)	RT22HC	22	-	-	Air	-	Experimental	Ljubljana, (Slovenia)
Zhao and Tan (2015)	RT22	19–23	-	-	Water and air	25.6*	Experimental	Laramie (USA)
Rahdar <i>et al.</i> (2016)	RT3HC	3	-	R134a	-	-	-	Ahwaz (Iran)
Aljehani <i>et al.</i> (2018)	78% (C <sub>14</sub> H <sub>30</sub> ) +22% expanded graphite	4–6	-	R410A	Ethylene glycol	3.2	Experimental	-
Li <i>et al.</i> (2018)	HS-W1/HS-	4.2-5.3 / 6-	-	-	Water	-	Experimental	-

	W2/Paraffin C15	6.5 / 10						
Said <i>et al.</i> (2018)	SP24E	24-25	-	-	Water	1.8 – 2.9	Experimental	-
Mousavi Ajarostaghi <i>et al.</i> (2019)	Ice	0	-	-	Ethylene glycol	-	Theoretical	-
Said <i>et al.</i> (2019)	24 E/26 E/29 Eu	24–25 / 26–27 / 29–31	-	-	-	1.81 – 2.875	Experimental	-
Zheng <i>et al.</i> (2019)	-	4-10	-	-	-	-	Experimental	Chengdu (China)
Aljehani <i>et al.</i> (2020)	78% (C <sub>14</sub> H <sub>30</sub> ) +22% expanded graphite	4–6	-	-	Ethylene glycol	100*	Theoretical	-
Loem <i>et al.</i> (2020)	RT18HC	18	-	-	-	-	Experimental	-
Nie <i>et al.</i> (2020)	RT18HC	17–19	-	-	Air	-	Experimental	-

\* Percentage increase to the reference used by the author.

## 2.4 Thermal energy storage focused on water heating

These studies also were analyzed in which PCMs were used to store thermal energy for posterior use. For application in water heating, it is necessary that the chosen PCMs be able to store heat and transfer it when requested or programmed.

Table 2 presents different studies related on thermal energy storage focused on water heating. The columns are the same of the Table 1.

Table 2. Studies on thermal energy storage focused on water heating

Authors	PCM	PCM's Melting Temperature (°C)	Tank Size (L)	Refrigerant	HTF	COP	Theoretical or Experimental Study	Location
Kaygusuz (1999)	Calcium chloride hexa-hydrate	28	-	R22	Water	2.7 – 4.5	Experimental	Trabzon (Turkey)
Erek <i>et al.</i> (2005)	Pure water	0	-	-	-	-	Experimental	-
Nallusamy <i>et al.</i> (2007)	Paraffin wax	60	47	-	Water	-	Experimental	-
Padmaraju <i>et al.</i> (2008)	Paraffin wax	58-62	48	-	-	-	Experimental	-
Benli and Durmus (2009)	Calcium chloride hexahydrate	32–45	335.65	R22	-	2.0 – 3.5	Experimental	Elazığ (Turkey)
Zhang <i>et al.</i> (2011)	Paraffin wax	45-48	-	-	-	3.25	Experimental	-
Niu <i>et al.</i> (2013)	RT6	6	11.5	R22	-	3.9	Experimental	-
Tores <i>et al.</i> (2013)	Paraffin wax	62	40	-	Water and propylene glycol	-	Theoretical	South Spain
Qv <i>et al.</i> (2015)	RT5HC	5-6	-	R22	Water	1.3 – 3.7	Experimental	Shanghai (China)
Mahfuz <i>et al.</i> (2014)	Paraffin wax	56.06–64.99	-	-	Water	-	Experimental	-

Youssef <i>et al.</i> (2017)	Organic pcm, paraffin	17	-	R134a	30% Ethylene Glycol and 70% water	4.80 – 4.99	Experimental	-
Zou <i>et al.</i> (2017)	RT44HC	43	-	R134a / R410A	-	3.46 – 3.74	Experimental	Guangdong (China)
Da Cunha and Eames (2018)	RT54HC	52-56	-	-	Water	4.81	Experimental	UK
Plytaria <i>et al.</i> (2018)	Q29/M91	29	1000	-	-	5.6 – 6.4	Theoretical	Athens (Greece)
Wu <i>et al.</i> (2018)	25% expanded graphite + and 75% paraffin	52–54	-	-	-	-	Experimental	-
Huang <i>et al.</i> (2019)	Sodium acetate trihydrate	50-52	60	-	-	-	Experimental	-
Real-Fernández <i>et al.</i> (2019)	S27	27	-	R134a	-	1.8- 2.15	Theoretical	-
Wang <i>et al.</i> (2019)	Paraffin	46.68	-	CO <sub>2</sub>	Water	2.27 – 2.51	Theoretical	Beijing (China)
Li <i>et al.</i> (2020)	Paraffin wax	44	-	R134a	Water	1.26 - 3.40	Theoretical	-
Wang <i>et al.</i> (2020)	Paraffin 1 / Paraffin 2	56/36	-	CO <sub>2</sub>	Water	1.73	Experimental	-

### 3. BRAZILIAN PERSPECTIVE

There are different applications for a heat pump integrated with a TES in Brazilian perspectives. As examples, meeting the demands of air conditioning, enabling the production of cold during the night (Baharun *et al.*, 2018). Similarly, the production of hot water for bathing during the day (Paulino *et al.*, 2019). These implementations, as presented in the literature, can enable the production of thermal energy (heat or cold) during times of greater availability of thermal energy in the environment and electrical energy in the national interconnected system.

For these applications, one of the main types of PCM that can be used within the Brazilian reality are paraffins, because they are, in a majority, low cost and accessible. Another material type that can be promising for use as TES is water / ice, due to the good performance in storing thermal energy by latent heat and also due to the abundance of water that Brazil has.

Approximately 58% of the studies presented in Tables 1 and 2 used paraffin as PCM (paraffin, paraffin wax and RT) and most of them used a commercial paraffin with high purity from Germany, which could result in higher costs for employability in Brazil. However, paraffin has ample space to be produced and processed in Brazil, reaching peculiarities to be adapted and used as PCM, given the Brazilian climate. Another benefit of using paraffin is the vast versatility of the material, which reaches a wide range of melting temperatures, giving the possibility of further choices in a project.

The use of the TES system during peak hours can lead to a decrease in energy costs due to the higher cost of the tariff during peaks and also bringing relief to the overload national interconnected system. Loading the TES overnight is a promising strategy to storage cold. As well as, loading TES around midday to storage heat.

An impasse observed in the studies is, according to the locations where the experiments were carried out, the condition of well-defined seasons with severe winters and very hot summers, influences the limitation of the type of PCM applied, causing sub-freezing, for example, as well as in the system in general. In the Brazilian climate, since the seasons go through transitions with less extreme temperatures, the TES system employed can achieve greater efficiency given the necessary conditions of use.

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