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Presented by: DRIZI Khadidja

Theme

Inclusion of phase change materials in conventional domestic refrigerator located in off-grid house.

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من قال انا لها "نالها" وانا لها وان ابت رغما عنها اتيت بها

الى الايادي الطاهرة التي ازالت من طريقي اشواك الفشل...الى من ساندتني بكل حب عند ضعفي ...الى من وضع المولى سبحانه وتعالى الجنة تحت قدميها ووقرها في كتابه العزيز... الى ملاكي في الحياة... امي

الى من رسم المستقبل بخطوط من الثقة والحب... الى من كلله الله بالهيبة والوقار... الى من علمني العطاء بدون انتظار وان النجاح لا يأتي الا بالصبر والإصرار... الى من احمل اسمه بكل افتخار... ابي

الى من لهم الفضل الكبير في تشجيعي وتحفيزي... الى من بهم أكبر وعليهم اعتمد ...والى من بوجودهم اكتسب قوة ومحبة...الى اخوتي سندي وملاذي عائشة، محمد الأمين، سمية، عبد الناصر، نهلة، اية، هديل، مراد، عبد العزيز، عبد الجبار

الى التي جعلت حظي في الدنيا كبير بوجودها ...الى قدوتي في الحياة... الى امي الثانية مهوال فاطمة

الى باعثة العزم والتصميم والإرادة...صاحبة البصمة الصادقة في حياتي ...خالتي مهوال عائشة

الى من فجعني برحيلهم جدي العربي وجدتي فاطمة الذين طالما تمنيت حضورهم لفرحتي...ولن فرق بيني وبينهم مفرق الاحباب...فاهدي ثمرة هذا الجهد الى روحهم الطاهرة

الى جدي قدور وجدتي بختة الذين لم يكفوا عن الدعاء لي بالنجاح احفظهما الله بعينيك التي لا تنام وبارك لهما في عمرهما

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الى كل من كان لهم أثر في حياتي ...الى كل من أحبهم قلبي ونسيهم قلمي

دريزي خديجة

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NOMENCLATURE

Φ: heat flux	**(W)**
S: area	**(m^3)**
λ: thermal conductivity of the medium	**(W /m K)**
h: convection heat transfer coefficient	**(W /m^2 K)**
T□: solid surface temperature	**(K)**
σ: Stefan Boltzmann constant	**(W/m^2K^4)**
ε: surface emissivity	/
Wcs: the isentropic work input to compressor	**(kJ/s)**
h2: the enthalpy	**(kJ/kg)**
V_{pcm} : volume of PCM	**(m^3)**
V_{comp}: volume of compartment	**(m^3)**
Vr: volume ratio	/
m_{pcm}: the mass of the PCM	**(Kg)**
ρ: density of PCM	**(Kg/ m^3)**
Q : the heat absorbed	**(J)**
L : latente heat	**(J/Kg)**
Cp: specific heat	**(KJ/Kg. K)**
Tm: melting temperature	**(K)**
T_{comp}: maximum temperature of the compartment	**(K)**
CpS: specific heat of solid	**(J/Kg.K)**
CpL: specific heat of liquid	**(J/Kg.K)**
T : time	**(s)**
P: power	**(W)**

Subscripts and exponents:

(LH)	latent Heat
(SH)	sensitive Heat
PCM	phase change material
MP	melting point

General introduction

General introduction

Since his presence on earth, man has been occupied with his continuous search for the the demands of life, and obtaining comfortable living conditions, this led to a large consumption of energy in its various forms such as (oil, gas, coal, electricity and others), as the latter is considered the engine of human activity , an element that enters into all daily human work and plays an important role in the development of all sectors.

Unfortunately, energy requirements are increasing. Moreover, energies the most widely used in the world is non-renewable and will eventually run out. More than that, they are highly polluted and producing greenhouse gases.

With the advancement of science, clean and sustainable energies have been found, known as renewable energies, which are five main types: solar energy, wind energy, hydropower, biomass, and geothermal energy, their common characteristic is that it is environmentally friendly and does not produce polluting emissions during the operation phase, thus helping to combat global warming.

Most renewables are not a constant source of energy. In addition, have a major drawback: their continuous fluctuation. However, they are extremely plentiful and the investment costs of the systems, which convertible, are constantly decreasing progressively reach the thresholds of competitiveness. Their significant contribution to sustainable development is likely to require extensively develop storage facilities

Thermal energy is one of the renewable energies, that has received special attention from scientists and researchers around the world in order to preserve it and develop methods of storing it, for example in the field of domestic refrigerators, which are considered one of the most devices demanding energy due to semi-continuous operation

PV-powered refrigerators have been used since 1981 in located off-grid for their refrigerant needs; however, photovoltaic systems require batteries with a large storage capacity to power a conventional refrigerator. But batteries used to store solar energy often fail after just a few years because the energy in the batteries is sometimes converted for other purposes, so the batteries last less time. In addition, replacing them is expensive and sometimes difficult to find, but they also contain toxic substances that cannot be easily disposed of.

In recent years, the design of solar refrigerators has taken a new step forward, which eliminates the need for expensive and problematic batteries used in energy. Engineers have thought of storing the sun’s heat during the day and running it overnight using mainly phase change materials (PCM) technology, also called latent heat storage materials technology. Therefore, it is important to exploit the stored energy for cold production, especially in remote rural and off-grid areas. The cooling mechanism by absorbing solar energy seems to be a promising way to improve living conditions in these areas in terms of health and economic.

The objective of the present work is to study the possibility of cold storage using phase change materials and to produce solar cooling in remote off-grid areas. These materials will be incorporated directly into the structure of the vapor compression refrigerator in order to minimize the number of compressor's starts at night and the reduction of battery capacity. In order to reach the objective mentioned in the present study, the carried-out work was divided into the following three chapters.

In the first chapter, a literature review of research works on solar refrigeration system are presented while focusing on PCM integration in solar refrigeration. At the end of this part, the suggested "hybrid home refrigeration system" is exposed.

In the second chapter, an overview of the heat transfer theory is conducted. The latter is supplemented by a detailed description of phase change materials and their applications. Moreover, this section is also dedicated to PCM uses in refrigeration system.

The third chapter is consecrated to the mathematical modeling of cold storage time for an off-grid domestic refrigerator partially filled with a PCM.

Finally, the work is completed with a general conclusion with a summary of the main obtained results and the most important recommendations.

Chapter 1. Solar energy-based refrigeration systems: state of the art

Introduction

This chapter presents a literature review of research works on solar refrigeration, with an emphasis on the PCM integration into solar refrigeration. It is also consecrated to the presentation of the proposed ‘'hybrid home refrigeration system".

1.1 State of the art

With an increasing application of phase-changing energy storage technology in the fields of energy conservation in buildings, refrigeration and air-conditioning which severely restricts the development of storage technology phase-change cold. Therefore, phase-change materials are becoming a research priority in the field of phase-changing energy storage. The classification and characteristics are briefly described. In this work. Since the 1980s,

The use of PCMs as means of thermal storage for solar power systems has attracted a lot of interest in recent years, because of fluctuations in the solar energy input. Several studies have been carried out on the use of PCMs in the refrigeration system.

Interesting studies have been reported on the integration of PCMs inside refrigeration systems where they are put into contact with the evaporator. Mention can be made of the work of Wang et al. [1] who performed an experimental study on a conventional refrigerator with PCMs mounted throughout its different parts. Results indicated the advantages of each PCM's location on the energy performance of the refrigeration system and obtained a COP improvement of 4% and a reduction of the refrigerant's sub-cooling of 8%.

Marques et al. [2] analyzed the influence that the orientation of PCM plates had on the energy performance of a typical refrigerator by placing the plates in different orientations. It was reported that the temperatures obtained by the vertical configuration were 2.4 ◦C greater than those given by the horizontal one.

Marques et al. [3] conducted research to investigate the impact of PCM thickness on the overall performance of a refrigerator. According to the findings of this research, the use of 5 mm of PCM enables an autonomy of between 3 and 5 h.

Alzuwaid et al. [5] introduced a water-based PCM in a refrigerated cabinet and noted a 5% improvement in the coefficient of performance, with a better control and stability of the air temperature inside the refrigerated cabinet.

Gin et al. [6] investigated what would happen to the functionality of a home freezer if a eutectic solution having a melting point of − 15.4 ◦C was introduced into the walls of a domestic freezer. According to the authors, the use of this PCM reduces the refrigerator’s energy consumption by around 7 %. In a separate research study.

Gin et al. [7] conducted an experiment to investigate how PCM panels with a mean temperature of − 15.4 ◦C affected the air temperature variations within a home freezer. They found evidence that the

PCM panels clearly contributed to controlling the rate at which the internal air temperature increased, which led to improved ability to preserve the food.

An interesting study on improving thermal performance of a domestic refrigerator was presented by Azzouz et al. [8] tested the effectiveness of a home refrigerator by placing water or a eutectic solution that had a melting point (MP) of − 3 ◦C in direct contact with the evaporator. The authors have focused into how the operating conditions of a home refrigerator affect its thermal performance. Accordingly, it was found that the COP increases by 5–15 % when the PCM is used, which depends on the internal load and the ambient temperature.

Elarem et al. [9] explored the possibility of using a phase change material (PCM) had a melting temperature of 4 ◦C in the evaporator of a home refrigerator. The conclusions reached from the numerical analysis were validated by the outcomes of the experiments. As a result, it was deduced that the modified prototype increases the COP by 8 % while simultaneously decreasing the amount of energy consumed by the refrigerator by 12 % and making the air temperature uniform in the compartment.

Yusufoglu et al. [10] examined the effects of integrating various PCMs (MP1 = 0 ◦C, MP2 = − 5.6 ◦C, MP3 = − 3.3 ◦C, and MP4 = − 3.9 ◦C) for two distinct models of domestic refrigerators in order to determine which combination would result in the lowest amount of electrical power usage. It has been determined that a refrigerator equipped with PCMs at the evaporator can achieve an overall reduction in energy consumption of up to 9.4 %. While selecting MP2 = − 5.6 ◦C as the melting point allowed for greater cost savings in comparison to other PCMs due to their respective melting points.

Leungtongkum et al. [11] discussed the state of the art of insulated box and refrigerated equipment-involving PCM for food preservation. The authors discussed the effect of some influencing factors (such as box shape, insulation material, PCM, operating conditions, etc.) on the modeling. Besides, some cold chain equipment was listed and reviewed.

Selvnes et al. [12] made a very comprehensive review on cold thermal energy storage applied to refrigeration systems adopting PCMs. Among the different sections, one referring to PCM in refrigerated vehicles and another one concerning the integration of PCM in packaging and containers can be found while the focus of the work was not on the refrigerated transportation.

Sonnenrein et al. [13] conducted an experimental study to evaluate the influence of using PCMs on the refrigeration performance of a household refrigerator. They investigated the effects of three different materials (namely water, paraffin, and a copolymer compound) separately on the condenser surface in order to reduce power consumption and to maintain the inside cabinet temperature at a more stable level. Experimental results illustrated that the integration of PCM could lower condensing temperature and consequently reduced energy consumption.

Bakhshipour et al. [14] carried out mathematical modelling of a refrigeration cycle using a PCM heat exchanger that was located at the location between the expansion valve and condenser. They investigated the effect of geometrical properties, PCM thickness and refrigerant properties on the performance of the cycle and the refrigerant temperature. Their results revealed an improvement in the COP of the refrigeration cycle up to 9.58%.

Ben Xu et al. [15] analyzed a novel air-cooled condenser using PCMs. They used PCMs as a thermal storage medium between the heat absorption and rejection processes on the steam and air sides. Their results showed that the steam condensation temperature reaches to the PCM melting temperature in the spray-freezing PCM air-cooled condenser regardless of variations in ambient air conditions, enhancing the air side heat transfer. Furthermore, the novel system provided additional net power generation of 10.8 MW as compared to the conventional air-cooled condenser.

Said et al. [16] experimentally investigate the use of thermal energy storage technique on the performance of air conditioning unit by incorporating PCMs into the condenser of an AC unit in order to store energy of PCMs during the night and to enhance the performant of the AC unit during the next daytime. Based on their results, it can shown that the COP of the PCM-based AC unit improved. Using horizontal and vertical PCM plates reduced energy consumption in the novel unit by around 11.2% and 9.8%, respectively as compared to the conventional air conditioning unit.

Cunjian pan et al. [17] proposed a novel PCM-based cooling system and modeled the finned heat pipe module for this system to estimate the system cost and to analyze the important parameters by employing a layered thermal assistance model. The results revealed that the latent energy of PCM has a first-order impact on the system cost. Furthermore, they showed that other parameters namely the PCM conductivity; PCM solidification time, driving temperature difference and the fin thickness have second-order effect on the system cost. Although most of the studies conducted using extended surfaces to investigate the encapsulation of the PCM, some studies have focused on using a cascaded arrangement of different PCMs in order to enhance overall heat transfer rate.

Farid and Kazawa [18] carried out the first investigative study using different PCMs arranged in the cascade, and indicated the beneficial results of this configuration. It is to noticed that PCMs are arranged in a decreasing order of their melting temperatures along the bed, which leads to the temperature difference being maintained between the heat transfer fluid and the latent heat storage system. This, in turn, enhances the overall heat transfer rate.

1.2 Hybrid home refrigeration system

A solar refrigerator with PCM is a type of refrigeration system that uses solar energy The refrigeration system is powered by an PV system. this system consists of

- Solar panels to generate electricity from sunlight, it would need to be connected directly to the compressor and the cooling system.
- A charge controller to regulate the electricity from the solar panels to the compressor and the cooling system, It is integrated with the refrigerator body.
- A high efficiency compressor to power the cooling system and to complete freezing of phase change materials in a period not exceeding the average sunlight.
- A thermal storage compartment to store the PCM.
- Insulation to reduce heat transfer and improve the efficiency of the cooling system.
- A controller to regulate the temperature and the operation of the cooling system.

The household refrigerator used has a capacity of 400L the external dimension are 146cm×60cm×60cm (hight,width,depth), and the internal dimension 142cm×56cm×56cm, the wall thickness approximately 4cm and the refrigerator is generally made of polystyrene (inner liner), polyurethane (insulating material).

The household refrigerator has two compartments the fresh-food and the frozen-food storage compartments having a volume of 280 L and 120 L, respectively.

Reservoirs of PCM are placed directly on the surface of the evaporator so that it can solidify completely during the period of operation of the compressor and in a short period, the PCM volume equals 50 of the volume of the refrigerator.

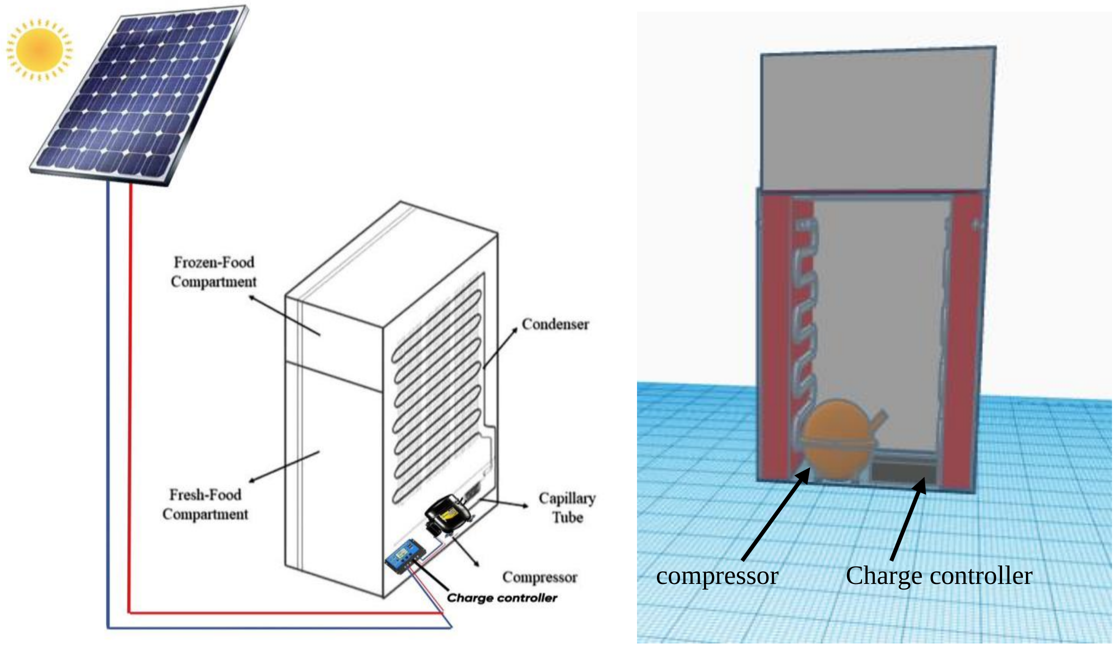

Figure 1-Hybrid home refrigeration system

The condenser and evaporator connected in the same way as in conventional refrigerator, the PCM placed between the evaporator and the refrigerator compartment.

The proposed location and layout of the PCM:

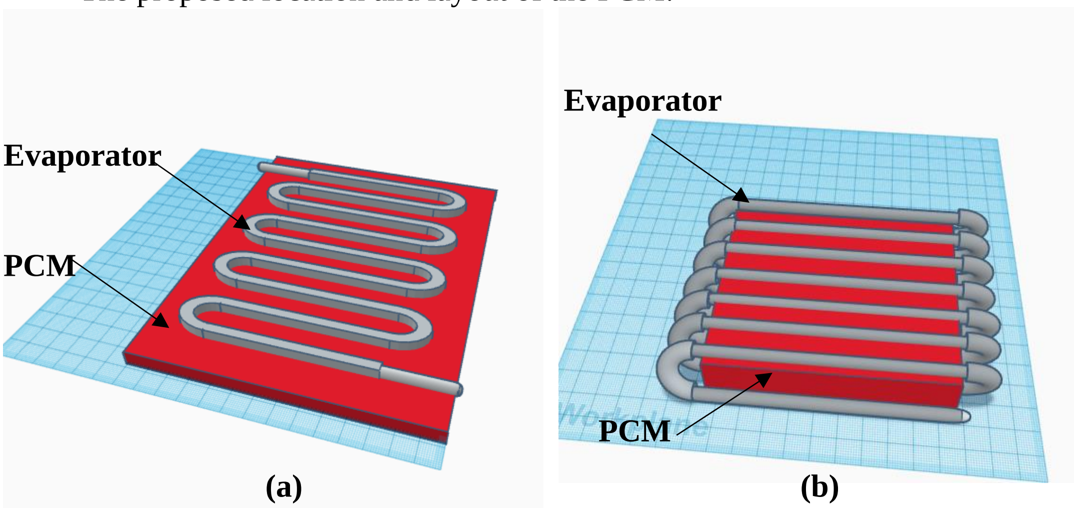

Figure 2-The proposed Design of evaporator coupled to a PCM.

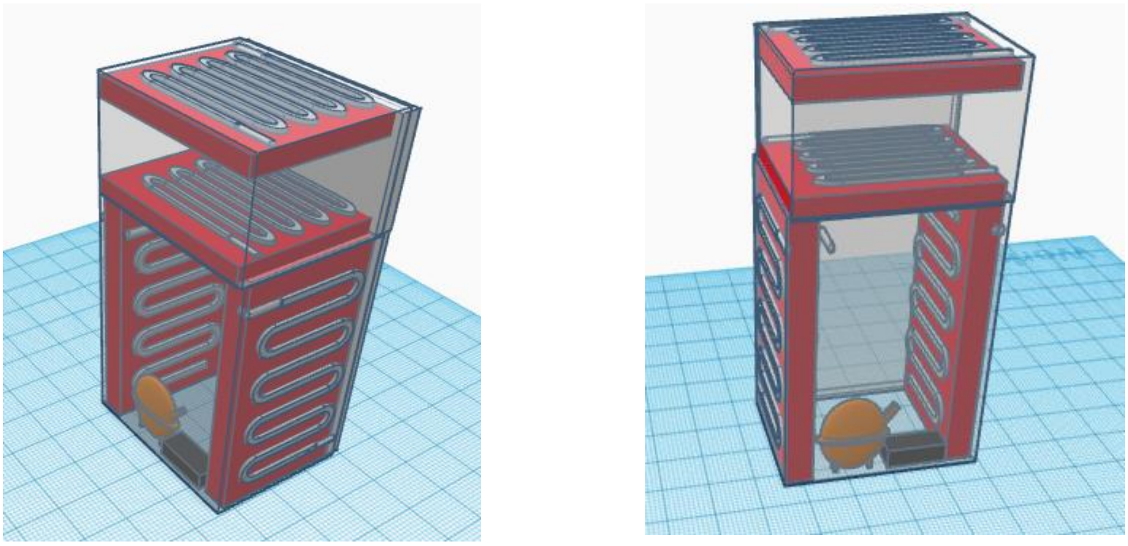

Figure 3-The schematic view of the proposed system and PCM location in the refrigerator compartment

Conclusion

In this chapter, a literature review of research works on solar refrigeration was presented. All carried out experiments have allowed concluding about the benefit of using phase change materials in household refrigerators to improve their efficiency. Moreover, a detailed presentation of the proposed hybrid home refrigeration system was carried-out supported by schematic sketches and drawings.

Chapter 2. Theoretical aspects of heat transfer, phase change materials and refrigeration systems

Introduction

This chapter is consecrated to some general aspects of the heat transfer theory. It includes notions of heat transfer modes (conduction, convection and radiation). The latter is followed by a general presentation of phase change materials (PCM), areas of their application and at last the use of PCM in refrigeration systems.

2.1 Basic concept

2.1.1 Heat

In physics, heat is called a particular form of energy. This equivalence of the heat and work is the first principle of thermodynamics. As a result, that energy, work and quantity of heat have the same unit: the joule [19].

At the basis of the study of heat transfer are the concepts of heat quantity and temperature difference. The transfer of heat from a part of a substance to another part, or from one body to another, carried out in the form of kinetic energy disorderly molecular agitation. This transfer is the result of a temperature difference between the two bodies. Heat spreads spontaneously from the body that has a higher temperature to the one with the lowest temperature, thus raising the temperature of this while lowering the temperature of the first, to the extent that the volume of the two bodys remains constant. This is the second principle of thermodynamics. This second principle highlights the notion of irreversibility: Heat will not be able to spread from a cold body to a hot body, unless work provided [19].

Example:

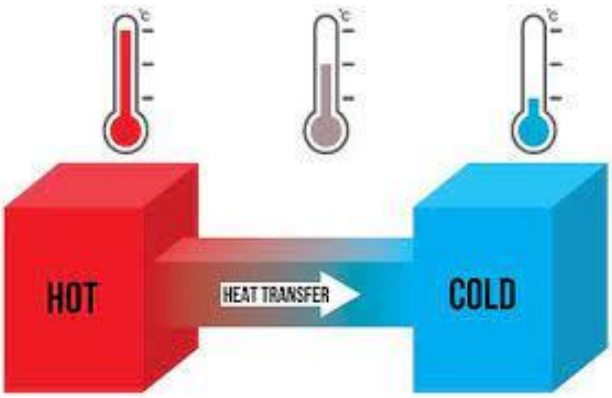

Figure 4-path of heat propagation in a wall [19]

2.1.2 Heat flux

Heat flows under the influence of a temperature gradient from high to low temperatures. The amount of heat transmitted per unit of time and per unit of area of the isothermal surface called heat flux density [19].

$$\Phi = \frac{1}{S} \times \frac{dQ}{dt} \qquad (2.1)$$

On the other hand, S is the area of the surface

The heat flux is the amount of heat transmitted on the surface S per unit of time:

$$\Phi = \frac{dQ}{dt} \quad (2.2)$$

2.1.3 Temperature

Temperature is the physical quantity that measures the degree of heat of a body. Of a medium. When two bodies placed in an adiabatic enclosure, the most heat yields heat to the coldest body, until both bodies have the same temperature. It is then said that we have reached the thermal equilibrium [19].

Temperature is a thermodynamic property of the body and measures agitation microscopic matter. According to kinetic theory, the temperature of a body is a function of the mean kinetic energy of translation of its molecules. The kinetic energy of a body is zero at a temperature called absolute zero [19].

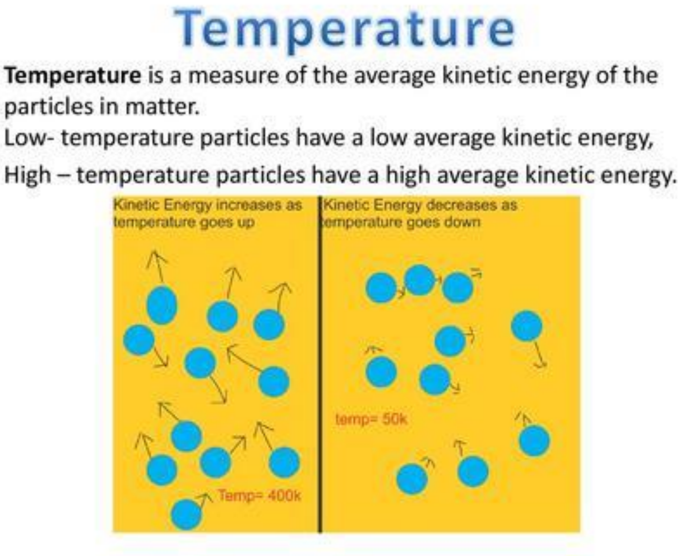

Figure 5-kinetic energy of cold and hot bodies [19]

The higher the temperature, the greater the kinetic agitation at the microscopic scale.

2.1.4 Heat units

We have seen that in physics, the amount of heat expressed in the same units as energy and labor, i.e. in joules (J). Calorie (Cal) is also used, defined as the amount of heat required to raise the temperature of 1 g of water from 14.5 °C to 15.5 °C at a pressure of 1atm [19].

Mechanical energy can be converted into heat by friction, and mechanical work needed to produce a calorie is called the “mechanical equivalent of the calorie” We have: 1Cal = 4.1855J [19].

2.2 Heat transfer

Thermodynamics can predict the total amount of energy a system must exchange with the outside world to move from one steady state to another. [20].

Thermal (or thermokinetics) aims to describe quantitatively (in space and over time) the evolution of the characteristic variables of the system, in particular the temperature, between initial and final steady state [20].

2.2.1 Definition

Heat transfer is a discipline of thermal engineering that concerns the generation, use, conversion, and exchange of thermal energy (heat) between physical systems. Heat transfer is classified into various mechanisms, such as thermal conduction, thermal convection, thermal radiation, and transfer of energy by phase changes. Engineers also consider the transfer of mass of differing chemical species (mass transfer in the form of advection), either cold or hot, to achieve heat transfer. While these mechanisms have distinct characteristics, they often occur simultaneously in the same system [21].

2.3 Mode of heat transfer

Historically, problems of energy transmission, and particularly of heat, have had a major impact on energy transmission. Of decisive importance for the design and operation of devices such as steam generators, furnaces, exchangers, evaporators, condensers, etc., but also for chemical transformation operations. Indeed, in some systems, is the rate of heat exchange and not the rate of chemical reactions, which determines the cost of the operation (case of highly endo- or exothermic reactions). In In addition, today, because of the relative increase in the cost of energy, we are in all cases to obtain the maximum efficiency of a plant for a minimum energy expenditure [22].

There are many problems of heat transfer, and we can try to differentiate between them. By the objectives pursued, the main ones of which are:

- The increase in energy transmitted or absorbed by a surface,
- Achieving the best efficiency from a heat source,
- Reducing or increasing the transfer of heat from one medium to another.

The potential for the transport and transfer of thermal energy is the temperature. If two material points placed in a thermally insulated medium are at the temperature, it can be said that there is no overall heat exchange between these two points in thermal equilibrium (this is indeed a thermal equilibrium because each of the material points emits a net thermal energy of the same module, but of opposite sign). Heat transfer within a phase where, more generally, between two phases, following three modes: [22]

- By conduction
- By convection

• By radiation

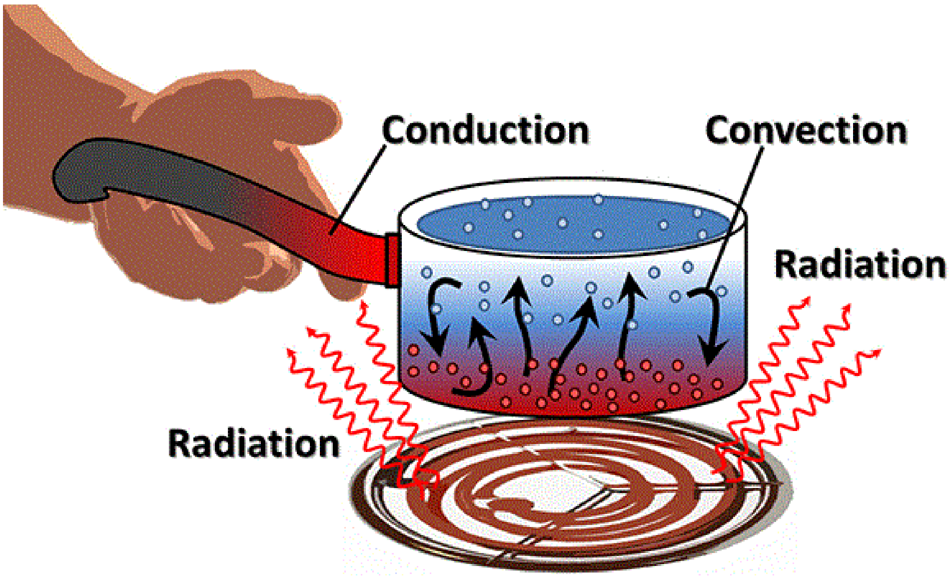

Figure 6-Mode of heat transfer [22]

2.3.1 Transfer by conduction

2.3.1.1 Definition

Conduction is a heat transfer in the mass of a material medium, the zones heat giving off heat to those that are less so. That's the case when you heat up. The end of a bar [20].

At the corpuscular level, the interpretation is as follows: a hot area occupied by particles at high velocity, by definition of temperature. The Brownian movement constantly moves particles from one area to another; but between areas with temperatures, the particles have different kinetic energies; the mixing has the effect of transfer kinetic energy of agitation, from hot areas to less hot areas. The macroscopic manifestation is a heat transfer. It is therefore a mechanism for shocks occurring [20].

The theory of conduction based on the Fourier hypothesis: the flux density is proportional to the Temperature gradient:]

$$\vec{\Phi} = -\lambda\, S\, \overrightarrow{grad}\,(T) \qquad (2.3)$$

$$\Phi = -\lambda\, S\, \frac{dT}{dx} \qquad (2.4)$$

With: **Φ:** Heat flux transmitted by conduction **(w)**

λ: Thermal conductivity of the medium **(W /m °C)**

x: Space variable in the direction of flow **(m)**

S: Area of the passage section of the heat flow **(m²)**

2.3.1.2 Application

Le transfert de chaleur par conduction caractérise tous les transferts de chaleur qui s'effectuent dans les parois séparant deux corps à des températures différentes. C'est le cas des surfaces d'échange des échangeurs de chaleur, mais c'est aussi celui des murs et vitrages d'un bâtiment, des cuves contenant des liquides chauds ou froids, des parois des fours, etc. Il est courant que les parois soient constituées de plusieurs matériaux ayant chacun un rôle spécifique (réfractaire, revêtement anticorrosion, isolant thermique, etc.) et qui sont des parois composites à travers lesquelles s'effectue le transfert de chaleur [23].

2.3.2 Transfer by convection

2.3.2.1 Definition

Convection is the phenomenon observed between a moving fluid and a wall, the main phenomenon in most heat exchangers [23].

The root cause is still agitation of fluid particles, but on a scale much less microscopic. The pieces of material in contact with the wall (hot by (example) are heated by conduction; the movement of the fluid carries these parcels back into the mass where they give up by mixing part of the heat received; others replace them at the wall and so on [23].

As for the movement of the fluid, it can have two causes. Alternatively, it's imposed from the outside. By a machine (pump, fan, compressor); it is forced convection. On the other hand, the contact of the fluid with the warmer or cooler wall creates mass differences volume, generating motion within the fluid; it is natural convection [23].

Strictly, even in forced convection, density differences create a flow parasitic, generally insignificant compared to the main flow. We're talking about convection. mixed when both phenomena are important [23].

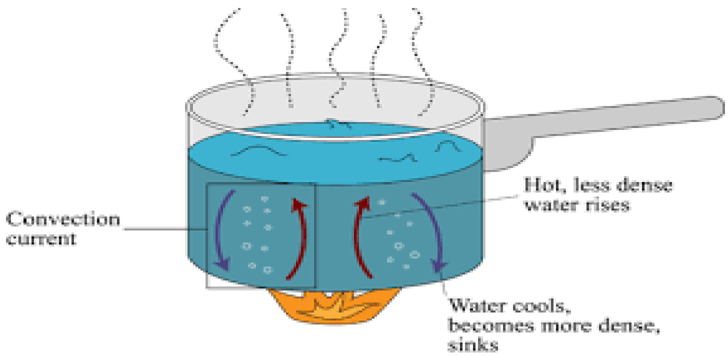

Figure 7-heat Transfer by convection [23]

Newton's law governs this transfer mechanism: [21]

$$\Phi = h\,S\,(T_{\square} - T_{\infty}) \qquad (2.5)$$

With **Φ:** Heat flux transmitted by convection **(w)**

h: Convection heat transfer coefficient **(W /m² °C)**

T□: Surface temperature of solid **(°C)**

T_∞: Temperature of the fluid away from the surface of the solid **(°C)**

S: Area of solid/fluid contact surface **(m)**

2.3.2.2 Application

The applications of convection heat transfer are far too numerous for that consideration could be given to mentioning all of them. They intervene every time you heat up or cooling a liquid or gas, whether it is boiling water in a pan, central heating radiator, and radiator associated with a car engine, or of the exchanger in a process, evaporator or condenser [24].

Convection applies even if a wall, such as mixed condensers or atmospheric refrigerants, or even hot air dryers, does not materialize the exchange surface [24].

2.3.3 Transfer by radiation

2.3.3.1 Definition

All bodies irrespective of their state: solid, liquid or gaseous, of absolute temperature T>O K, emit electromagnetic waves; they are said to emit "thermal radiation". Besides, to the process of emitting thermal radiation is added a process of absorption of radiation electromagnetic sources from the environment of these bodies. Their thermal state is then governed by the balance sheet of the emissions and removals processes. Thermal radiation corresponds to a heat transfer that does not require any support material; this is how the earth is "heated" by the thermal radiation of the sun [23].

This is the case with the energy that comes to us from the sun. The physical interpretation is as follows: everybody emits particles called "photons"; these move at the velocity of the, light and carry an energy depending on their "wavelength" A body C emitting photons in all possible directions, some of them are received by the other body C',   possibly wholly or partially absorbed, Of course, the C body also emits photons, some of which will be received and absorbed by C. The net balance results in an energy exchange between C and C’ [23].

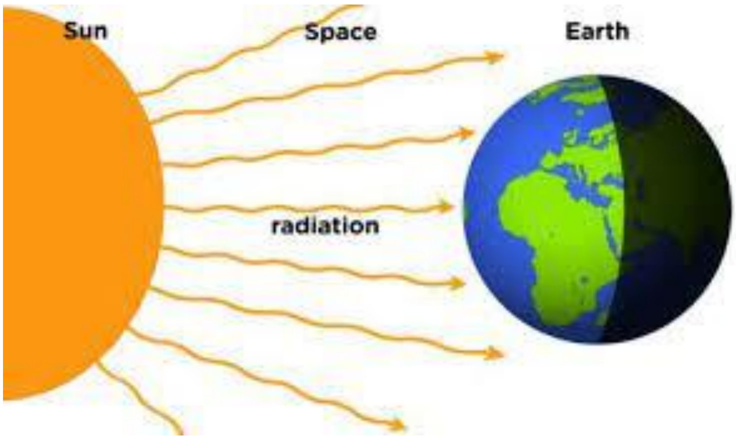

Figure 8-heat transfer by radiation [23]

Stefan-Boltzmann’s law gives the heat flux exchanged between surface S and the environment [21]

$$\Phi=\sigma\ \varepsilon\ S\ (T_{s}^{4}-T_{\infty}^{4}) \qquad (2.6)$$

with Φ: Power transferred (W)

σ: Stefan Boltzmann constant = 5. 67*10^{-8}W/m²K⁴

ε: surface emissivity

S: Area traversed (m2)

T_{s}: Surface temperature (K)

T_{∞}: Temperature of the environment surrounding the surface (K)

2.3.3.2 Application

Infrared radiation used in many industrial processes. Her action on the material is mainly thermal and the main applications related to this radiation are: [24]

- Drying (paper, cardboard, textiles, etc.)
- Cooking (dyes, primers, coatings...);
- Heating. (Before forming various materials, heat treatments, welding, and heating of workstations...);
- Polymerization (inks, coatings, packaging...);
- Sterilization (pharmaceutical bottles, various food products...).

Ultraviolet radiation consists of photons with energy of the order of magnitude of the energy of atomic bonds.

These act on matter by moving electrons to energy levels higher. When the material exposed to radiation is sensitive to radiation, there are chemical reactions. The part of the ultraviolet radiation absorbed by the material that not used in the chemical reaction transformed into heat. In practice, this heating remains low, the ultraviolet radiation is mainly used in the field of plastic film cross-linking, and polymerization of organic products such as printing inks, lacquers and varnishes, operations that are often called improperly drying [24].

2.4 Definition of phase change materials (PCMs)

A phase change material (PCM) is a substance that releases/absorbs sufficient energy at phase transition to provide useful heat/cold. Generally, the transition will be from one of the first two fundamental states of matter – solid and liquid to the other [25].

The energy released/absorbed by phase transition from solid to liquid, or vice-versa, the heat of fusion is generally much higher than the sensible heat. By melting and solidifying at the phase change temperature (PCT), a PCM is capable of storing and releasing large amounts of energy compared to sensible heat storage. Heat is absorbed or released when the material changes from solid to liquid and vice versa or when the internal structure of the material changes; PCMs are accordingly referred to as [25].

latent heat storage (LHS) materials. PCMs are using in many different commercial applications where energy storage and/or stable temperatures are required, including, and among others, heating pads, cooling for telephone switching boxes, and clothing [25].

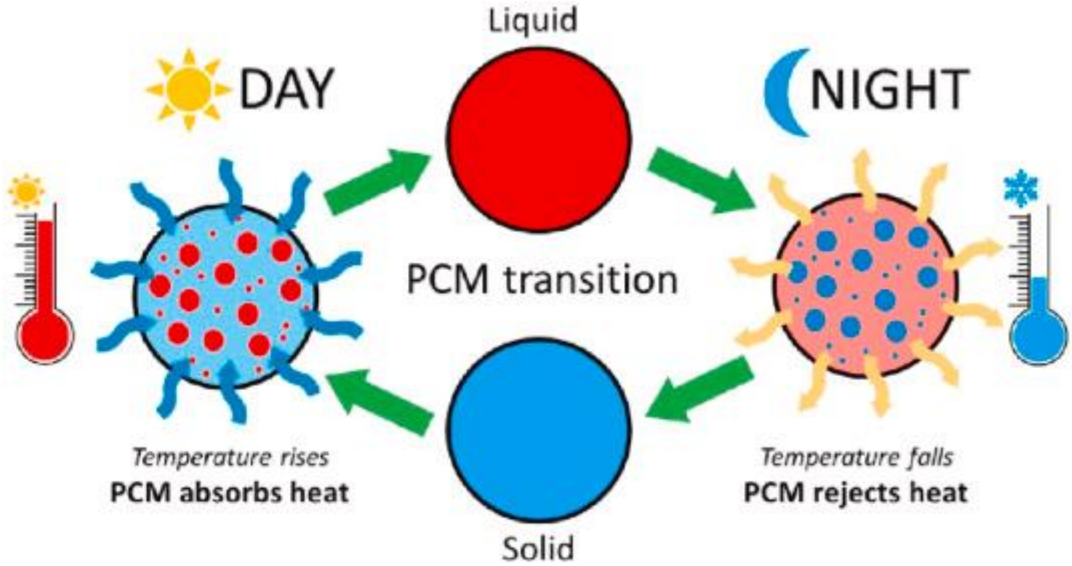

Figure 9-PCM transition [25]

2.5 General information on phase change materials

2.5.1 Principle of PCMs

Any material, solid or liquid (or gaseous) has the ability to store or transfer energy in the form of heat. There are 2 types of heat transfer (or transfer thermal) [26].

2.5.1.1 Heat Transfer by Sensitive Heat (HS)

In this case, the material in question may transfer or store energy by changing its own temperature, without changing state. The quantity used to quantify the HS exchanged by a material is the Mass Heat, noted Cp and expressed in J/ (kg.K) [26].

Example: Cp water = 4180 J/(kg.K) means that it takes 4186 joules to raise 1 kg of water from 1 °C (valid at temperatures close to 20 °C) [26]

2.5.1.2 Heat Transfer by Latent Heat (HL)

In this case, the material may store or release energy by a simple change of state, while maintaining a constant temperature, that of the change of state. The quantity used to quantify the HL exchanged by a material is the Latent Heat of Change of Phase rated Lf (f for fusion) for a Liquid/Solid phase change, and Lv (v for vaporization) for a Liquid/Vapor phase change. This isexpressed in terms of J/kg [26].

Example: L f water = 330 × 10 3 J/kg means that melting, i.e. casting, of 1 kg ice at a (constant) temperature of 0 °C will require an energy of 330000 joules or 330 Kj [26].

2.5.2 Types of PCMs

There are three main families of PCMs: organic compounds, inorganic and eutectic mixtures. Each of these families can be broken down into subgroups, whose behaviors very different physical and chemical influences the design of the storage system [27].

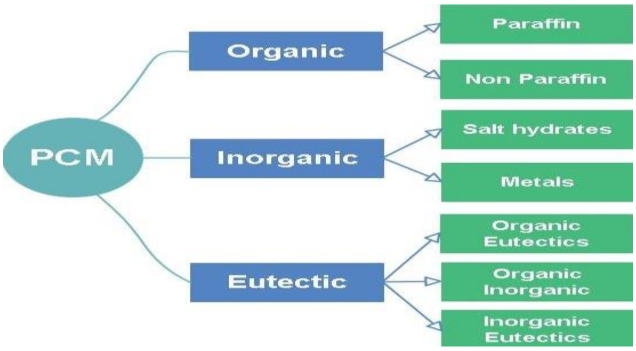

Figure 10-Classification of phase change materials [27]

2.5.2.1 Inorganic PCMs

Inorganic materials or substances have a temperature or range of melting temperatures between -100 °C and +1000 °C. The most used are: water, aqueous solutions of salt, hydrated salts, mixtures of salts, mixtures of metals. They have several advantages: they have a high latent heat and high conductivity thermal. They are non-flammable and have an affordable investment cost. They are in. generally readily available. Major problems encountered in their use are related to segregation, corrosion and super-cooling [27].

Salt hydrates: are inorganic salts that contain water and have the formula is AB.nH2O. During charging, the dehydration of the salt takes place [28].

Metals: Examples include Potassium (Tfusion = 63.2 °C), Bi58Sn42 (Tfusion = 138 °C) or Lithium (Tfusion = 186 °C) [28].

Salts: Salts are neutral ionic compounds formed from cations and anions. Salts pure and mixtures of non-eutectic salts generally exhibit a broad spectrum of melting temperatures and latent heat varying according to their type. Fluorides and Chlorides thus exhibit a higher latent heat than nitrates or sulfates. The best known salts are nitrates such as NaNO3 (Tfusion = 307°C), KNO3 (Tfusion = 333°C) or LiNO3 (Tfusion = 250°C) [28].

2.5.2.2. Organic PCMs

Organic materials have a temperature or temperature range between 0°C and 150°C. The most widely used are based mainly on paraffin, fatty acids and sugar alcohols. They have some disadvantages compared to the advantages of PCMs inorganic: they have a lower solid and liquid conductivity, they have a lower lower latent heat of fusion, they are flammable. On the other hand, they have advantages. they are available in a wide range of temperatures and are compatible with conventional building materials, they are chemically stable. They're not. reagents most of the time and they are recyclable [27].

Paraffins: Organic paraffinic PCMs are derivatives of hydrocarbons of the type alkanes of the formula CnH2n+2. They are in the form of chains (n-paraffinic hydrocarbons) or branches (iso-paraffinic hydrocarbons). Paraffin is tasteless and non-toxic. The latent heat as well as the phase change temperature of the paraffin increase [29].

With the length of their molecular chains. The increase in the number of atoms of carbon from 1 to 100 increases the stored energy from 58 to 285 kJ/kg and the temperature of phase change from 90 to 390°C [29].

Non-paraffinic: The family of organic non-paraffinic PCMs includes fatty acids, esters fats, alcohols and glycols. The MCPs from this family are not taken from the petroleum derivatives. Fatty acids, for example, are extracted from animal and vegetable oils, their formula General chemical is Cn (CH2)2nCOOH [29].

The people esters are derived from the direct esterification of fatty acids, which allows them to be separated vegetable oils. They exist in different forms such as vinyl stearate, vinyl stearate, butyl stearate, methyl hexadecanoate, palmitate isopropyl This family of PCMs has excellent features in terms of energy storage without superfusion. In addition, these materials are not derived from hydrocarbons, which gives them particular interest in reducing the environmental footprint. Their main disadvantage is also their low thermal conductivity [29].

2.5.2.3. Eutectic PCMs

It is usually a mixture of organic and inorganic PCMs. It consists of several pure PCMs. These materials have two major advantages: a net melting point similar to a pure substance and latent volumetric temperatures slightly higher than those of pure organic compounds. Two major drawbacks are that little information is available on the thermal properties of these materials and that little information is available on the thermal properties of these materials. Used in industrial systems [30].

2.5.3 Comparison between different types of PCM

Several authors have presented a comparison of the advantages and disadvantages organic, inorganic and eutectic materials.

PCM Type	Advantages	Disadvantages
Organics (Paraffin wax, fatty acids and vegetable oils)	• Availability in a wide temperature range • High heat of fusion • No subcooling • No segregation • Stable after many cycles • Chemically and physically stable • Compatibility with a wide range of containers • Corrosiveness materials • Environmentally safe, nonreactive • Recyclable	• Low thermal conductivity • Large volume change during phase transition except for some fatty acids. • Unstable at high temperatures • No sharp phase transition • Noncompatible with the plastic containers • Costly in pure form • Low enthalpy • Flammable • Different toxicity levels
Inorganic (Salt hydrates)	• High thermal storage capacity • Good thermal conductivity • Low cost • Available easily • Sharp melting points • Low vapour pressure • Nonflammable	• Show subcooling • Considerable change in volume • Show phase segregation • Incompatible with metallic containers
Eutectic	• Sharp melting and boiling points • Higher volumetric storage density than the organic PCM	• Costly • Limited data available for thermo-physical properties

Figure 11-advantages and disadvantage different types of PCM [27]

2.5.4 Different shapes of PCMs

It must have an effective heat exchange between the PCM and the coolant in order to high efficiency of energy storage. Therefore, PCMs are generally contained such as either large heat transfer area or high convection heat transfer coefficient between Pack PCM and the heat transfer fluid is possible [31].

2.5.4.1 Microencapsulation

The aim of the microencapsulation technique is to trap the material with a change of in spheres with diameters ranging from 5 to 300µm, before being incorporated into the target material or constructive system. The spheres (capsules) are usually in polymer such as melamine formaldehyde [31].

The microencapsulation technique consists of preparing an oil emulsion (PCM) more polymer in water, a surfactant is then added to the mixture with a catalyst (PH variation, temperature variation, pressure variation). This allows the migration of a polymer condensate at the oil/water interface thus forming the microcapsules of the PCM, figure I-8 (a and b). This technique is the most suitable for integrating PCMs into the building materials such as concrete.

Indeed the shape of microencapsulated PCMs can be assimilated to fine aggregates. Moreover, the stability of the majority polymers used for microencapsulation of PCMs after several cycles of heating/cooling is an asset to ensure the durability of thermal comfort [31].

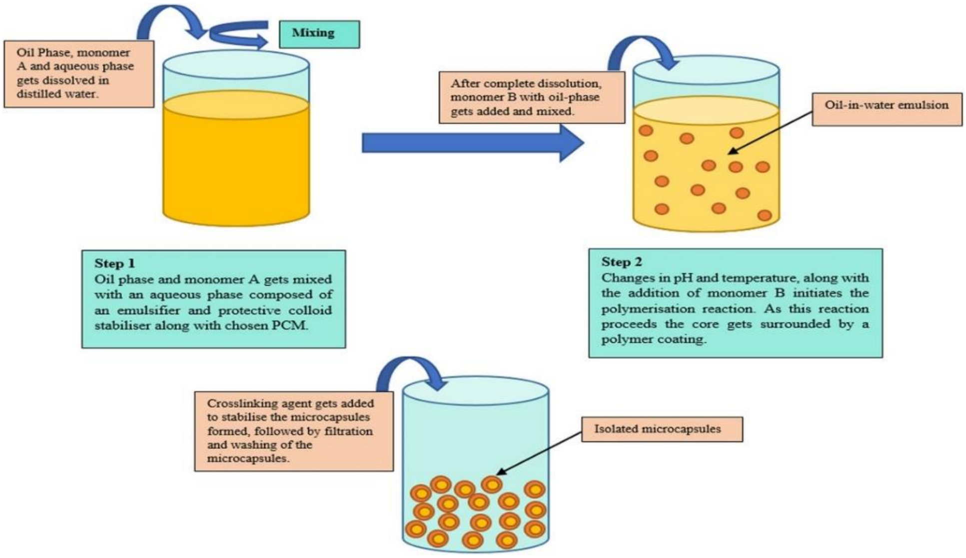

Figure 12-General microencapsulation process [31]

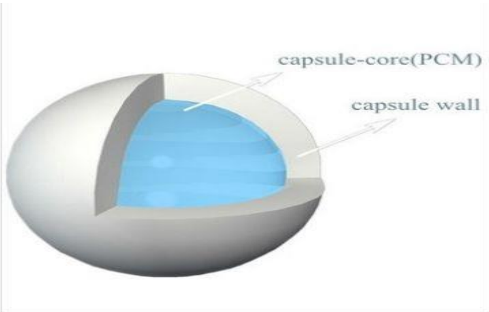

Figure 13-the PCM microencapsulated [31]

2.5.4.2 Macroencapsulation

The macroencapsulation technique consists of integrating MCPs into macrocapsules before being incorporated into the intended building materials and systems. Macrocapsules may be in the form of bags, plastic bottles, sachets, panels. Containers generally have a high thermal conductivity in order to increase the heat exchange (storage/return) and are rigid in order to limit the risk of leakage MCP during solid/liquid phase change [31].

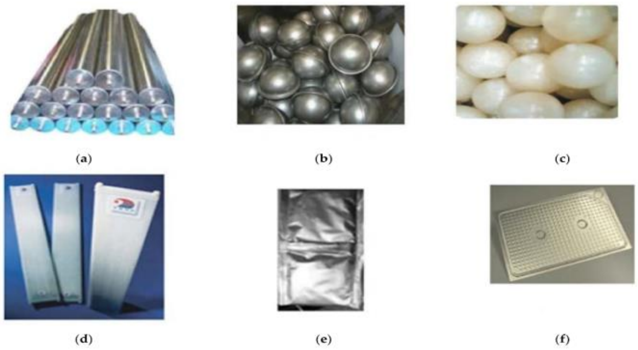

Figure 14-Examples of different container shapes used for PCM encapsulation: (a) tubes, (b) metal spheres, (c) PCM spheres, (d) rectangular PVC panels, (e) aluminum pouches, (f) flat panel [31]

2.5.4.3 Direct incorporation

Direct incorporation consists of directly integrating the PCM into the material construction or the intended constructive system without prior preconditioning (microencapsulation or macroencapsulation). is the possible leakage of the PCM during its transition to the liquid state of the material, or target design system in case of low leakage. Moreover, in the case of: incorporation of MPC into hydraulic binders such as plaster or concrete inhibit the phenomenon of hydration [31].

Immersion: This technique consists of immersing the hardened target material in a bath of PCM in liquid phase; the PCM will penetrate by capillarity into its porous network. This technique has the same drawback as the direct incorporation technique [31].

2.5.5 Choice of PCM

Criteria will therefore be defined to facilitate the selection of an MCP for a specific application [31].

Thermal considerations

- The level of phase change temperature depending on the application.
- The value of latent heat of fusion (>130 kJ / kg to be competitive).
- High thermal conductivity for charge and discharge kinetics Quick.
- Low vapor pressure to minimize pressure holding problems storage systems.

Physical properties

- Slight change in volume during the state change for the dimensioning of the storage and its pressure holding.
- A large density for the PCM to carry out a storage sufficient in the smallest possible volume.
- A congruent fusion when using a compound body

Kinetic considerations

- Fast charge and discharge kinetics.

- No overfusion, which destroys the kinetics and alters the possibility of destocking.

Stability and compatibility considerations with other materials:

- Stability of the body during thermal cycling.
- Compatibility with the materials of the storage tank for each phase for
- Avoid all problems of corrosion, chemical or electrochemical reactivity.

Chemical considerations

- Chemical stability of bodies with time and temperature levels.
- Good crystallization rate and non-flammability and non-toxicity.

Economic considerations

- Reasonable cost and availability [31].

2.6 Thermo physical properties of PCM

2.6.1 Definition of PCM properties

The following definitions include terms used to describe the behavior of the MCP: and the properties of the PCM. The purpose of these definitions is to provide the designer with a reference practical for terms used in PCM technology [32].

Amorphous: Without defined shape; not crystalline. Amorphous solids can be considered like superfluid. They don't have a sharp melting point like a solid crystalline. Glass is a typical amorphous [32].

Auto-ignition temperature: The temperature at which a material will ignite automatically and will maintain combustion in the absence of spark or flame [32].

Calorie (cal): The amount of heat needed to raise 1 gram of water one degree Kelvin at 288 K. It is equivalent to 0.00396 Btu or 4.184 Joules [32].

Volume Expansion Coefficient: The ratio of volume change per degree ° Kelvin volume at 273 Kelvin [32].

Crystal: A solid in which atoms or molecules are arranged according to a pattern repetitive regularly spaced. Most crystalline solids consist of millions of tiny single crystals called grains. A: any single crystal, no matter the size of a grain. Crystals of the same substance all have the same structures geometric; the corresponding crystalline faces have the same angles to each other. The crystals vary considerably, depending on the type and strength of the bonds between the atoms, the ions or constituent molecules. The crystal structure was used as a basis for X-ray identification, electron. And neutron diffraction methods [33,34].

The crystals can be classified into geometric types which include: single cubic, cubic to c-body, cubic with centered faces, tetragonal, orthorhombic, monoclinic, triclinic and hexagonal [35].

Flammable: Property of a material that allows it to oxidize quickly and release the heat of combustion when exposed to a flame or fire, and allows a continuous combustion after removal of the external ignition source [35].

Flash Point: The temperature at which a combustible liquid or vapor ignites and burns. The resulting fire is transient and self-extinguishing. There are several tests of common flashpoints and each gives a different value for the same substance [35].

Freezing point: The temperature at which a material solidifies upon cooling to starting from a melted state. The freezing point is not always the same as the freezing point. Merger [35].

Calorific capacity at constant pressure (Cp): amount of heat required to raise a unit of mass of homogeneous material of a unit of temperature with a pressure maintained constant. The calorific capacity is expressed as energy per unit mass per temperature change unit [35].

Hygroscopy: Property of a material that allows it to absorb and retain water from the air ambient. The properties of a material can be significantly altered by water absorbed [35].

Melting point: The temperature at which the liquefaction of a solid occurs. Alloys and impure materials have a melting range. The melting point is not always the same than the freezing point [29].

Oxidizing agents: Generally sources of oxygen. Some materials are chemically so formed that they can supply oxygen to a reaction, even in the absence of air [35].

Phase change: the change of a material into a physically distinct state and mechanically separable (as a defined solid state) into another distinct form (as a liquid), phase changes consist of four types: solid-solid, solid-vapor, solid-liquid and liquid-vapor [35].

Prandtl number (Npr): The ratio of the dynamic viscosity of the fluid μ of a liquid to quotient of its thermal conductivity k and its calorific capacity Cp .This property influences the heat convection capacity of a fluid. Fluids such as liquid metals have low Prandtl (Npr) numbers and are effective for convection heat transfer applications [35].

Rayleigh Number (R): The ratio of the force of gravity to the viscous force. The number De Rayleigh is defined as [35].

Superfusion: The process of cooling a liquid below temperature solid-liquid equilibrium without any formation of the solid phase. Superfusion when an only phase is present is called one-phase superfusion. Superfusion in the presence of both solid and liquid is a two-phase superfusion. The amount of overfusion depends on the particular material and the surrounding environment. The best way to reduce super cooling is to ensure that all crystalline material of

net background origin. The crystalline germs present in the molten mass tend to enucleate the solid phase when the heat is removed. Nucleation catalysts are available for some materials [36].

2.6.2 Desirable PCM performance

There is no perfect PCM material because no material has all the desirable properties to the degree that would be ideal. An PCM is supposed to provide isothermal control for a melody specified in a particular application. Clearly, there are trade-offs in the selection of the most suitable PCM for a selected application [32].

The often unacceptable properties of PCMs can be corrected. For example, metal fillers can be used to increase the thermal conductivity of PCMs few drivers. Nucleation catalysts can be found for materials which are cool down to overcome this common problem. Changes in volume may be compensated in several ingenious ways. If the space limitations are more weight, a metal PCM can provide the same heat of fusion over a density base than almost any PCM, and has the advantage of thermal conductivity high [32].

In general, the ideal PCM would have the following characteristics: [32]

- High heat of fusion: This property defines the available energy and can be significant by weight or volume. Some PCMs are attractive anyway.
- Reversible solid-liquid transition: the composition of the solid and liquid phases must be Even so.
- High thermal conductivity: This property is required to avoid gradients thermal. Loads are used to improve system performance.
- High specific heat and density characteristics.
- Long-term reliability during repeated cycles
- Reliable freezing behavior.
- Small volume change during phase transition.
- Low vapor pressure.

2.7 Application of PCMs

2.7.1 Transport of food products

PCMs are used in the agri-food, pharmaceutical and medical industries to keep temperature changes to a minimum for foods, medicines, or sensitive components, e.g. in the case of blood transport. They are mainly in the form of plastic "small bags" containing the selected material arranged closest to the product to be stored [37].

2.7.2 Medical application

In the medical sector, one of the main applications is the transport of blood and organs. Containers used for this work purposes similar to those explained before. Other medical applications may be hot or cold pads to treat local pain in the body [38].

Figure 15-example of Medical application [38]

2.7.3 Textile industry

Phase-change materials can be used in many areas industry applications that are suitable for optimizing thermal comfort physiological clothing, mattress coutil, sleeping bags. It then becomes particularly important to find materials whose melting and crystallization are very close to the surface temperature of the human body [37].

The materials used for this kind of application are usually paraffins, which have an average temperature of 30-34°C, which becomes very comfortable for the body human [37].

2.7.4 PCM in domestic refrigerator

Constant refrigerators have poor performance energy. These appliances consume 18 billion kWh, which is equivalent to 20% of total energy consumption. Residential electricity consumption and thus contribute to the greenhouse effect by 2.25 billion tons of CO_2/year [39].

The integration of phase-change materials into a home refrigerator is an innovative and economical technological solution to reduce this energy consumption and limit peak power in electricity. The effect of the greater thermal inertia brought by these materials will also consequence of limiting the number of stop start to privilege certain hours of operation during the day and stabilize the temperature for better conservation Food [39].

2.7.5 PCM in cooling of electronic components

The most common cooling system currently is convection (natural or forced) of ambient air. An PCM can absorb a large amount of heat by melting, which makes it a very interesting alternative to dissipate the energy emanating from the electronics. Since the fusion phenomenon occurs within a range of close temperature, it is then possible to control the temperature of these components. It would therefore suffice to juxtapose these components with an PCM enclosure that would allow dissipate energy produced by heat sources for a given period of use. This system is particularly well suited to the cyclical use of electronic equipment. The PCM can then release its heat (by settling) during the period of inactivity [39].

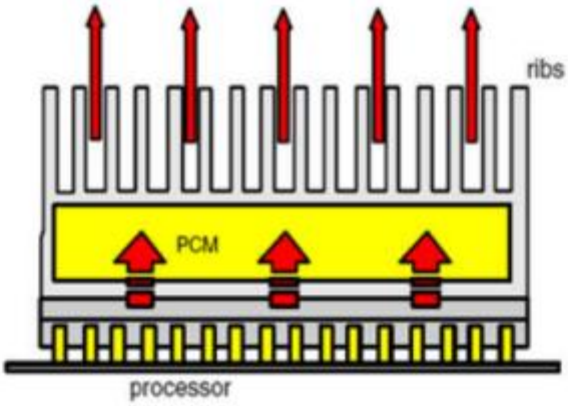

Figure 16-example of electronic equipment cooled using a PCM [39]

2.7.6 Application to buildings

The use of phase-change materials (PCMs) for heat storage in buildings is one of the first applications of these materials currently, the The majority of studies on phase-change materials (PCM) are directed towards: [40]

- Their use, when integrated into the building envelope, for heating applications.
- Their integration into the shell of buildings with low thermal inertia in order to improve summer comfort

2.7.7 Solar energy storage by PCM

The solar energy depends on the weather during the day, which depends on the season, so a back-up energy is required to ensure the continuity of operation of the solar installations. The use of phase-change materials for energy storage used during critical periods was an inadequate solution. One of the applications the most important of solar energy is water heating. This application requires two components: a solar collector and a thermal storage unit. With the goal to increase the thermal storage capacity, water can be replaced by a material with phase change (PCM), characterized by a relatively high latent heat of fusion [39].

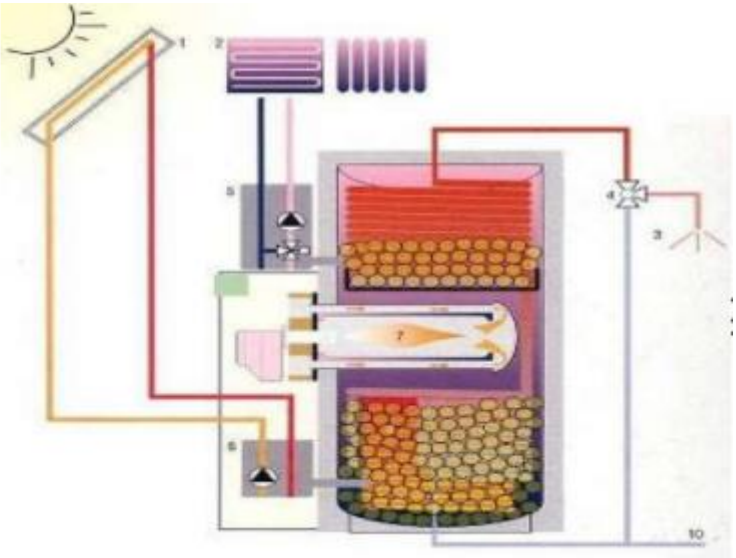

Figure 17-Energy storage in a solar collector using a PCM [39]

2.7.8 Air cooling with PCM

Another avenue explored is that of plate-shaped air/PCM exchangers. Zalba and al experimented with enclosures containing PCM plates and in which the air Ventilation is forced to be cooled on contact with plates [41].

2.7.9 PCM in Packaging and Display Cabinets

In order to provide consumers with high-quality products after harvest, the cold chain is essential. The design of appropriate packaging ensures product quality at all stages of storage, transportation, and sale to consumers. The temperature of perishable products must be maintained within certain limits to provide high-quality products. To mitigate the temperature rise, packaging can be designed with insulated containers, PCM, and modified atmosphere packaging (MAP) and stored on refrigerated shelves. PCM are used in freezers to protect products at optimal temperature during power outages and to reduce energy consumption by reducing the duty cycle of the compressor [42].

Figure 18-commercial Display Cabinets [42]

2.7.10 PCM in Refrigerated Transport

Maintaining the desired temperature inside a refrigerated trailer is challenging due to vehicle movement, frequent door openings, and inadequate tailgate insulation . To ensure optimal thermal comfort without temperature fluctuations, innovative methods such as hybrid technology with the use of PCM in conventional refrigeration improve the quality and economy of transportation . Figure 4 shows the refrigerated vehicle model used for the experimental study with a 3D cad model of the vehicle with PCM for the numerical analysis performed by [42].

Figure 19-(a) Commercial refrigerated truck; (b) 3D model of the PCM incorporated truck [42]

2.8 Latent heat energy storage in PCMs

2.8.1 Principle

Latent heat storage is a thermal storage solution that harnesses heat latent of a Phase Change Material (PCM), in other words its ability to change from the solid state to the liquid state (fu ion) under the effect of heat.

The phase change energy is absorbed during PCM melting and is released during of its solidification. This solution requires the use of a heat transfer fluid to transfer the heat from the source to the storage unit. The PCM undergoing cycles of fusion/solidification, it cannot be used directly as a transfer fluid. The heat transfer technologies are diverse: finned tube exchanger, heat exchanger multitubes, PCM encapsulation [43].

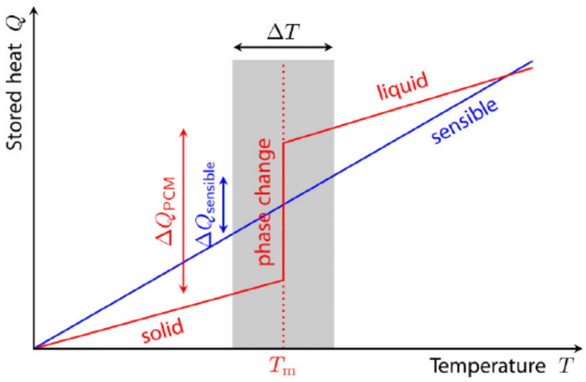

Figure 20-Graphic representation of energy storage by the PCM [43]

When a hot fluid comes into (indirect) contact with the MCP, the MCP changes from a solid state in the liquid state (fusion) capturing the heat of the fluid. Conversely, if the fluid is cold, the MCP in solidifying restores its heat to the heat transfer fluid.

For industrial applications where the storage temperature is above 100-150°C, it is mainly paraffins, fatty acids and hydrated salts which are considered. The enthalpies of fusion of these compounds vary from 150 to 600 KJ/L [43].

2.8.2 Performance

The energy density of PCMs (in KWh/m3) is higher than that of the systems of sensible heat storage, which gives latent heat storage systems a greater compactness and less heat loss [43].

One of the main constraints of PCMs is their low thermal conductivity ($\lambda << 0.5$ W/m.K), limiting charging and discharging speeds and imposing large surfaces exchange [43].

2.8.3 Benefits:

- Mitigate the gap between the production of waste heat (energy recovery) and the needsin heat on the site (use of recovered energy)
- High energy density compared to sensitive storage.
- Stable discharge temperature.
- Chemically stable.
- Nontoxic.

2.8.4. Disadvantages:

- Low thermal conductivity ($\lambda << 0.5$ W/m.K) limiting charging, discharge, and imposing large exchange surfaces.
- Limited storage time (thermal losses).
- Limited melting temperature.
- Relatively high costs compared to sensitive storage.

2.8.5 Applications:

Thermal storage by PCMs can be used in various applications and industries [43]:

- Heat storage from waste heat recovery.
- Storage of heat produced by solar thermal.
- Storage on a heating network (in development).
- Cold storage (refrigeration and transport of agro-food products or pharmaceuticals, for example).
- Fresh storage for air conditioning.

2.9 refrigeration machine

2.9.1 Definition:

The term 'refrigeration' defined as the process of removing heat from a substance under controlled conditions. It also include the process of reducing and maintaining the temperature of a body below the general temperature of its surrounding [44].

In other words, the refrigeration means a continued extraction of heat from a body whose temperature is already below the temperature of its surroundings. Theoretically, a refrigerator is a reversed heat engine or a heat pump, which pumps heat from a cold body and delivers it to hot body. This substance, which works in heat pump to extract heat from a cold body and to deliver it to a hot body, is, called a refrigerant [44].

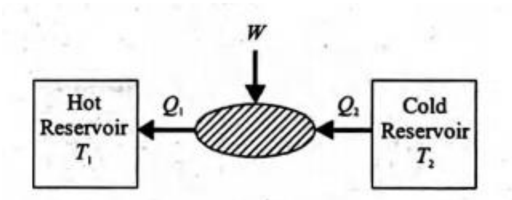

Figure 21-Energy diagram of a refrigerating machine [44]

2.9.2 Components of a domestic refrigerator:

The basic idea behind a refrigerator is very simple: It uses the evaporation of a liquid to absorb heat. You probably know that when you put water on your skin it makes you feel cool. As the water evaporates, it absorbs heat, creating that cool feeling. Rubbing alcohol feels even cooler because it evaporates at a lower temperature. The liquid, or refrigerant, used in a refrigerator evaporates at an extremely low temperature, so it can create freezing temperatures inside the refrigerator. There are five basic parts of any refrigerator (or air-conditioning system): [45] Compressor Heat-Exchange Pipes – Serpentine or coiled set of pipes outside the unit. Expansion Valve Heat-exchange pipes- Serpentine or coiled set of pipes inside the unit Refrigerant - Liquid that evaporates inside the refrigerator to create the cold temperatures [45].

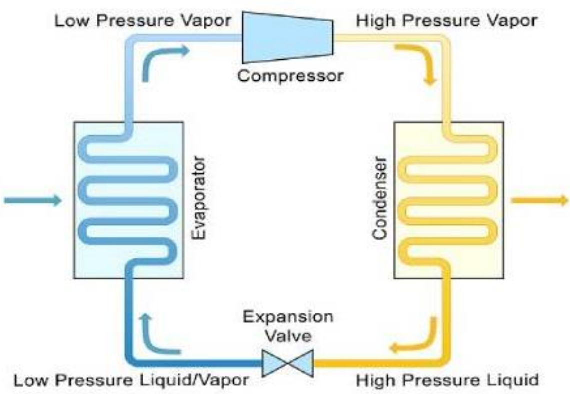

Figure 22-Components of a domestic refrigerator [45]

Compressor: Compression is the first step in the refrigeration cycle, and a compressor is the piece of equipment that increases the pressure of the working gas. Refrigerant enters the compressor as low-pressure, low-temperature gas, and leaves the compressor as a high-pressure, high-temperature gas [40].

Compression can be achieved through a number of different mechanical processes, and because of that, several compressor designs are used in HVAC and refrigeration today. Other examples exist, but some popular choices are: [40]

1. Reciprocating compressors
2. Scroll compressors
3. Rotary compressors

Figure 23-compressor [40]

The condenser: The condenser, or condenser coil, is one of two types of heat exchangers used in a basic refrigeration loop. This component is supplied with high-temperature high-pressure, vaporized refrigerant coming off the compressor. The condenser removes heat from the hot refrigerant vapor gas vapor until it condenses into a saturated liquid state, a.k.a. condensation. After condensing, the refrigerant is a high-pressure, low-temperature liquid, at which point it’s routed to the loop’s expansion device [46].

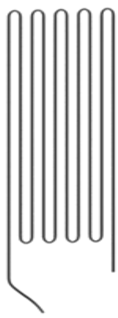

Figure 24-Condenser [46]

The expansion device: These components come in a few different designs. Popular configurations include fixed orifices, thermostatic expansion valves (TXV) or thermal expansion valves (pictured above), and the more advanced electronic expansion valves (EEVs). But regardless of configuration, the job of a system’s expansion device is the same - create a drop in pressure after the refrigerant leaves the condenser. This pressure drop will cause some of that refrigerant to quickly boil, creating a two-phase mixture. This rapid phase change is called flashing, and it helps tee up the next piece of equipment in the circuit, the evaporator, to perform its intended function [46].

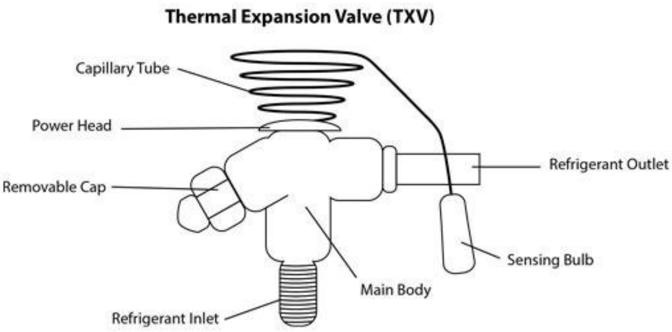

Figure 25-expansion valve [46]

The evaporator: The evaporator is the second heat exchanger in a standard refrigeration circuit, and like the condenser, it's named for its basic function. It serves as the "business end" of a refrigeration cycle, given that it does what we expect air conditioning to do – absorb heat. This happens when refrigerant enters the evaporator as a low temperature liquid at low pressure, and a fan forces air across the evaporator's fins, cooling the air by absorbing the heat from the space in question into the refrigerant [46].

After doing so, the refrigerant is sent back to the compressor, where the process restarts. Moreover, that, briefly, is how a refrigeration loop works. If you have any questions about the refrigeration cycle or its components and how they work, give us a call. We have been helping customers get the most out of their HVAC and refrigeration equipment for nearly 100 years [46].

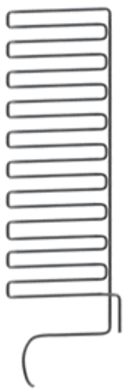

Figure 26-Evaporator [46]

2.9.3 How does a refrigerator work?

In the refrigeration cycle, there are five basic components: fluid refrigerant; a compressor, which controls the flow of refrigerant; the condenser coils (on the outside of the fridge); the evaporator coils (on the inside of the fridge); and something called an expansion device. Here is how they interact to cool your food [47].

1. The compressor constricts the refrigerant vapor, raising its pressure, and pushes it into the coils on the outside of the refrigerator.
2. When the hot gas in the coils meets the cooler air temperature of the kitchen, it becomes a liquid.
3. Now in liquid form at high pressure, the refrigerant cools down as it flows into the coils inside the freezer and the fridge.
4. The refrigerant absorbs the heat inside the fridge, cooling down the air.
5. Last, the refrigerant evaporates to a gas, and then flows back to the compressor, where the cycle starts all over.

2.9.4 Analysis of domestic refrigerator cycle

A simple analysis of standard vapor compression refrigeration can be carried out by assuming a) steady flow b) negligible kinetic and potential energy changes across each component and c) no heat transfer in connecting pipelines. The steady flow energy equation is applied to each of the four components. The p-h diagram of vapor compression refrigeration was shown [48].

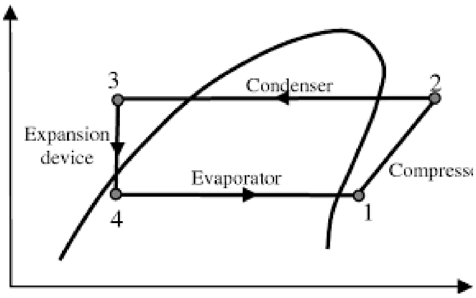

Figure 27-domestic refrigerator cycle [48]

Compressor

The isentropic work input to compressor (Wcs, kJ/s) is expressed as:

$$Wcs = mr\,(h2-h1) \qquad (2.7)$$

Where h2 is the enthalpy of refrigerant at the outlet of compressor (kJ/kg)

The actual compressor work (Wc , kJ/s) is given as

$$Wcs = Wcs / \eta s \qquad (2.8)$$

Where ηs is the isentropic efficiency.

Condenser

The heat rejected by the condenser (Q_{cond} , kJ/s) to the atmosphere is given as

$$Q_{cond} = m_r (h2 - h3) \quad (2.9)$$

Where h3 is the enthalpy of refrigerant at the outlet of condenser (kJ/kg)

Capillary Tube

In the capillary tube the enthalpy remains constant (isenthalpy process), therefore,

$$h3 = h4$$

Dossat RJ et al. (2002) measured the performance of the refrigeration cycle as coefficient of performance (COP) and is the refrigerating effect produced per unit of work required [37].It is expressed as:

$$COP = Q_{evap} / Wc \quad (2.10)$$

Fatouh M and El Kafafy (2006) defined the volumetric cooling capacity (VCC, kJ/m3) as the refrigerating effect per unit volume flow rate at the inlet to the compressor [37]. It is expressed as

$$Q_{evap} / (mr / Vs) \quad (2.11)$$

Where Vs is the specific volume at inlet to the compressor (m3 /kg).

Compressor pressure ratio (pr) is given as:

$$Pr = P_{dis} / P_{suc} \quad (2.12)$$

Where, P_{dis} = refrigerant vapor pressure at the compressor discharge (kN/m2)

P_{suc} = refrigerant vapor pressure at the compressor suction (kN/m2)

2.9.5 Types of refrigeration systems

a. Vapor compression refrigeration systems,

1. Domestic refrigeration systems
2. Air conditioning systems

b. Vapor absorption refrigeration systems

c. Solar energy based refrigeration systems

d. Air cycle refrigeration systems

e. Steam and vapor jet refrigeration systems

f. Thermoelectric refrigeration systems, and

g. Vortex tube

Among the above most refrigeration system, most commonly used refrigeration is vapour compression refrigeration system [48].

2.10 solar Domestic refrigeration system using PCM

Refrigeration and air-conditioning systems have an important impact on the environment and actively participate to the global warming. Nevertheless, environmental regulations established by the Montreal Protocol has relatively decreased the use of some chloro fluorocarbon refrigerants (CFCs) that strongly attack the atmospheric ozone layer. Additionally, their directly emitted greenhouse gases (GHG) have been mitigated by the hydrocarbon refrigerants. However, their indirect emissions are high due to the ever-increasing energy consumption of these appliances. Special attention to the global environmental issues and rapidly increasing cost of electricity are driving the demand for finding a frugal and viable solution for energy saving. Because of the extreme necessity to diversify energy sources, the search for energy recycling methods through the utilization of thermal losses from equipment has become fundamental [49].

Energy efficiency and standard of eco-friendliness are the two important issues confronting the refrigerator manufacturers. Hence, rigorous evaluation of domestic refrigerators for checking the energy efficiency and its sensitivity to variables such as type of refrigerant, size of compressor, ambient temperatures and type of insulation is necessary. This is where the application of phase change material (PCM) in refrigerators is highlighted to enhance their performance. The heat energy associated with PCM is more like a natural phenomenon and isothermally process of the energy storage, the PCM's enthalpy of fusion can be employed in different thermal applications. Today, the use of PCM holds the key to one of promising sustainable energy techniques of storing thermal energy. This thermal energy can be used on domestic refrigerators to increase their performance and the quality of food stored inside. Reduction of temperature fluctuation and improvement of system performance is the main goals of using PCMs in refrigeration systems [49].

Conclusion

In this chapter, were identified and presented studies on phase change materials, their definition, classification and importance. The latter is supplemented by the description of the benefits and advantages of thermal energy storage with latent heat using phase changing materials. The application of PCMs was also introduced in the household refrigerator to improve its efficiency.

Chapter 3. Mathematical modeling of cold storage time

Introduction

This chapter is devoted to the mathematical modeling of the cold storage time for a conventional domestic refrigerator located in an off-grid house filled with phase change materials.

3.1 Materials and methods

3.1.1 Materials

A) Household refrigerator

The household refrigerator used for this study contains a fresh food compartment and a frozen food side, the conventional system is a double-door refrigerator with the following characteristics

- Cabinet: a capacity of 400L, with external dimensions of (146×60×60 cm) and the internal dimension (142×56×56 cm), the fresh-food and the frozen-food storage compartments having a volume of 280 L and 120 L, respectively
- Evaporator: free convection, plate evaporator (90×44 cm)
- Condenser: free convection
- Compressor: 300W
- Refrigerant: R134a.
- On/off control and auto defrost

B) PCM

In this work, we will study seven types of PCM with different weight percentages.

Table 1-Physical characteristics of the phase change materials

PCM	melting temperature (K°)	density (Kg/m³)	latent heat (KJ/Kg)	specific heat (J/Kg K°)
Water	273	997	334	4180L 2052S
Water-glycol wt%	270	1008	334	3700L 2000S
Ethylene glycol	262	1110	181	2400L 2200S
N-dodeccane	263	780	216	2220L 1480S
N-tridecane	267	750	179.39	2206L 1979S
RT2	271.5	790	174	2.000
RT-9HC	263	880	250	2.000

3.1.2 Methods:

To test the performance of PCM in a domestic fridge, a fridge with a capacity of 400 L with two compartments was chosen; frozen-food compartment with a volume of 120 L and fresh food compartment with a volume of 280 L.

maximum temperature of the compartment for the frozen food (comp= -24°C) and for fresh-food (Tcomp=8°C), Seven types of PCM would be considered every time was taken a percentage of PCM of the volume of the freezer and fresh food, and these percentages ranged between (10%, 20%, 30%, 40%, 50%).

3.2 Mathematical modeling of cold storage time

In order to carry out this study, it is necessary to determine PCMs volume, mass, absorbed heat and cold storage time in both fresh-food and frozen-food compartments.

All formulas used in the calculations are reported in Tab.2

Table 2-Used formulas

Parameter	Formula	Symbols meaning
Volume	$V_{pcm}=\frac{V_{comp}\times V_{rt}}{100}$	**(m³)**
Mass	$m_{pcm}=V_{pcm}\times\rho$	**(Kg)**
the heat absorbed	$Q = L\times m_{pcm} + m_{pcm}\times C_{pS}\times(T_e - T_{ST}) + m_{pcm}\times C_{pL}\times(273 - T_e)$	**(J)**
Storage time	$T=\frac{Q}{P}$	**(s)**

- **Volume of PCM:**

$$V_{pcm}=\frac{V_{comp}\times V_{rt}}{100} \quad (3.1)$$

Where: Vpcm – the volume of PCM (m^3), Vcomp - volume of compartment (m^3) and Vrt- the volume ratio.

- **The mass of the PCM**

$$m_{pcm}=V_{pcm}\times\rho \quad (3.2)$$

Where : mpcm - the mass of the PCM (Kg), Vpcm- the volume of PCM (m^3) and ρ- the density of the PCM (Kg/ m^3).

- **The heat absorbed**

$$Q = L\times m_{pcm} + m_{pcm}\times C_{pS}\times(T_m - T_{comp}) + m_{pcm}\times C_{pL}\times(273 - T_m) \quad (3.3)$$

Where: Q is the absorbed heat in (J), L - latent heat in (J/Kg) , mpcm- the mass of the PCM in (Kg), Cp- the specific heat in (KJ/Kg.°K), Tm- the melting temperature in (°K), Tcomp – the maximum temperature of the compartment in (°K), CpS- the specific heat of solid in (J/Kg.K) and CpL- the specific heat of liquid in(J/Kg.K).

- **The Storage time**

$$T=\frac{Q}{P} \quad (3.4)$$

Where : T - time in (s), Q - the heat absorbed in (J) and P- the power in (W)

3.3 Result of calculation

The calculated volumes of PCMs in both fridge compartments are presented in Tab. 3 and 4.

Table 3—Volume of PCMs in frozen-food

Vrt	Volume of fozen-food compartment, L	Water	ethylene-glycol	water-glycol 10 wt%	n-dodecane	n-tridecane	RT2	RT9HC
0.1	**120**	0.012	0.012	0.012	0.012	0.012	0.012	0.012
0.2	**120**	0.024	0.024	0.024	0.024	0.024	0.024	0.024
0.3	**120**	0.036	0.036	0.036	0.036	0.036	0.036	0.036
0.4	**120**	0.048	0.048	0.048	0.048	0.048	0.048	0.048
0.5	**120**	0.06	0.06	0.06	0.06	0.06	0.06	0.06

Table 4— Volume of PCMs in fresh-food

Vrt	Volume of fresh-food compartment, L	Water	ethylene-glycol	water-glycol 10 wt%	n-dodecane	n-tridecane	RT2	RT9HC
0.1	**280**	0.028	0.028	0.028	0.028	0.028	0.028	0.028
0.2	**280**	0.056	0.056	0.056	0.056	0.056	0.056	0.056
0.3	**280**	0.084	0.084	0.084	0.084	0.084	0.084	0.084
0.4	**280**	0.112	0.112	0.112	0.112	0.112	0.112	0.112
0.5	**280**	0.14	0.14	0.14	0.14	0.14	0.14	0.14

The calculated mass of PCMs in both fridge compartments are presented in Tab. 5 and 6.

Table 5 — Estimated mass of PCMs in frozen-food compartment

Vrt		Water	ethylene-glycol	water-glycol 10 wt%	n-dodecane	n-tridecane	RT2	RT9HC
0.1	**m(Kg)**	11.964	13.32	12.096	9.36	9	9.48	10.56
0.2		23.928	26.64	24.192	18.72	18	18.96	21.12
0.3		35.892	39.96	36.288	28.08	27	28.44	31.68

0.4		47.856	53.28	48.384	37.44	36	37.92	42.24
0.5		59.82	66.6	60.48	46.8	45	47.4	52.8

Table 6 — Estimated mass of PCMs in fresh-food compartment

Vrt		Water	ethylene-glycol	water-glycol 10 wt%	n-dodecane	n-tridecane	RT2	RT9HC
0.1	**m(Kg)**	27.916	31.08	28.224	21.84	21	22.12	24.64
0.2		55.832	62.16	56.448	43.68	42	44.24	49.28
0.3		83.748	93.24	84.672	65.52	63	66.36	73.92
0.4		111.66	124.32	112.896	87.36	84	88.48	98.56
0.5		139.58	155.4	141.12	109.2	105	110.6	123.2

The estimated heat absorbed by PCMs in both fridge compartments are presented in Tab. 7 and 8.

Table 7 — Estimated heat absorbed by PCMs in frozen-food compartment

Vrt		Water	ethylene-glycol	water-glycol 10 wt%	n-dodecane	n-tridecane	RT2	RT9HC
0.1	**Q(J)**	4585179.072	3143520	4682362	2423491	2054232	2104560	3146880
0.2		9170358.144	6287040	9364723	4846982	4108464	4209120	6293760
0.3		13755537.22	9430560	14047085	7270474	6162696	6313680	9440640
0.4		18340716.29	12574080	18729446	9693965	8216928	8418240	12587520
0.5		22925895.36	15717600	23411808	12117456	10271160	10522800	15734400

Table 8—Estimated heat absorbed by PCMs in fresh-food compartment

Vrt		Water	ethylene-glycol	water-glycol 10 wt%	n-dodecane	n-tridecane	RT2	RT9HC
0.1	**Q(J)**	10257455.04	7042728	10575533	5590166	4415754	4269160	7047040
0.2		20514910.08	14085456	21151066	11180333	8831508	8538320	14094080
0.3		30772365.12	21128184	31726598	16770499	13247262	12807480	21141120
0.4		41029820.16	28170912	42302131	22360666	17663016	17076640	28188160
0.5		51287275.2	35213640	52877664	27950832	22078770	21345800	35235200

The obtained cold storage time for several PCMs in frozen-food and fresh-food compartments are respectively reported in Tabs. 9 and 10.

Table 9 — Estimated cold storage time for several PCMs in frozen-food compartment

Vrt		Water	ethylene-glycol	water-glycol 10 wt%	n-dodecane	n-tridecane	RT2	RT9HC
0.1	**T(S)**	15283.9302	10478.4	15607.87	8078.304	6847.44	7015.2	10489.6
0.2		30567.8605	20956.8	31215.74	16156.61	13694.88	14030.4	20979.2
0.3		45851.7907	31435.2	46823.62	24234.91	20542.32	21045.6	31468.8
0.4		61135.721	41913.6	62431.49	32313.22	27389.76	28060.8	41958.4
0.5		76419.6512	52392	78039.36	40391.52	34237.2	35076	52448

Table 10—Estimated cold storage time for several PCMs in fresh-food compartment

Vrt		Water	ethylene-glycol	water-glycol 10 wt%	n-dodecane	n-tridecane	RT2	RT9HC
0.1	**T(s)**	34191.5168	23475.76	35251.78	18633.89	14719.18	14230.53	23490.13
0.2		68383.0336	46951.52	70503.55	37267.78	29438.36	28461.07	46980.27
0.3		102574.55	70427.28	105755.3	55901.66	44157.54	42691.6	70470.4
0.4		136766.067	93903.04	141007.1	74535.55	58876.72	56922.13	93960.53
0.5		170957.584	117378.8	176258.9	93169.44	73595.9	71152.67	117450.7

3.4 Results analysis and discussion

This section presents and analyzes the preliminary results of a study on a two-compartment refrigerator with the difference in the temperature of the two compartments. PCM is deeply analyzed keeping in mind different product mass.

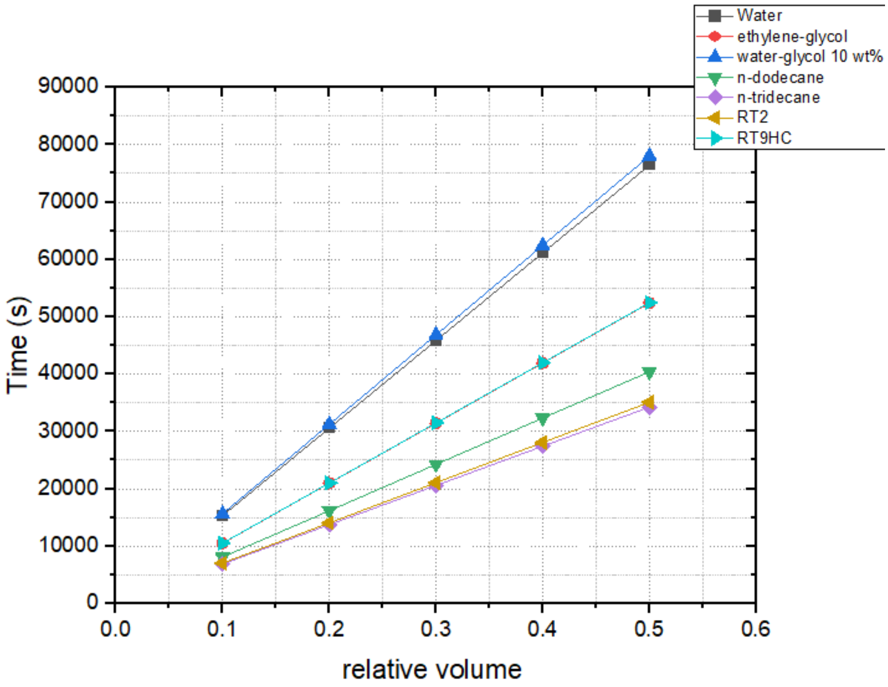

Figure 28-Cold storage time according to PCM to frozen-food compartment volume ratio for different types of PCM

Figure 28 shows the cold storage time according to PCM and frozen-food compartment volume ratio for different types of PCM

All seven charts show a linear trend, cold storage time proportional to relative volume, storage time increases with increasing relative volume.

For a volume ratio, 0.4 found that the cold storage time, for water-glycol 10wt T=62431s, and for water T=61135s, can say that water and water-glycol 10wt% ,the parmet to have a very prolonged freezing time compared to the other PCM, after found the ethylene-glycol and RT-9HC with the same prolonged freezing time. after n-dodecane it has a short cold storage time, finally n-tridecane and RT-2 have the shortest cold storage time.

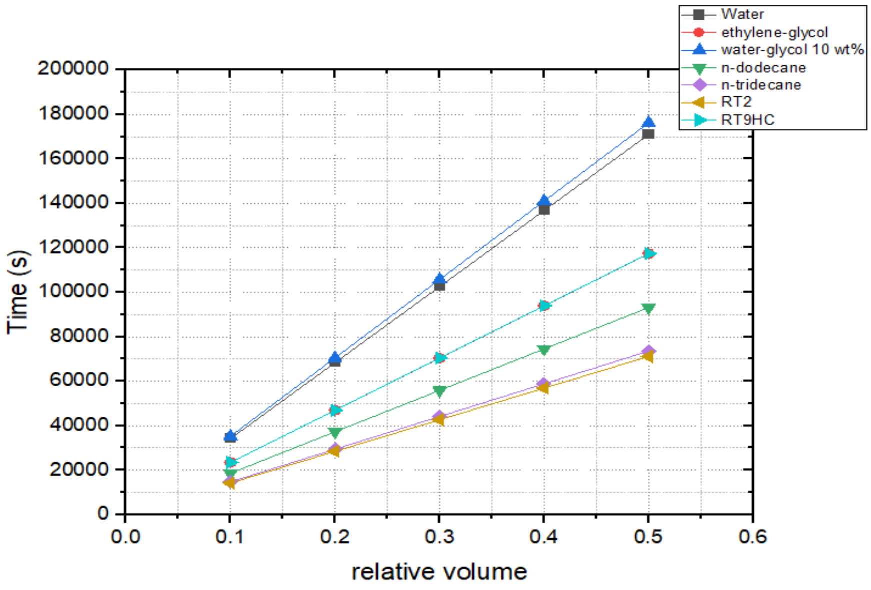

Figure 29-Cold storage time according to PCM to fresh-food compartment volume ratio for different types of PCM

Figure 29 shows the cold storage time according to PCM to fresh-food compartment volume ratio for different types of PCM.

All seven charts show a linear trend, cold storage time proportional to relative volume, storage time increases with increasing relative volume.

For a volume ratio, 0.4 found that the cold storage time for water-glycol 10wt% t=141007s and for water t= 136766s, can say that water and water-glycol 10wt% have a very prolonged freezing time compared to the other PCM, after found the ethylene-glycol and RT-9HC with the same prolonged freezing time. After n-dodecane it has a short cold storage time, finally n-tridecane and RT-2 have the shortest cold storage time.

Table 11 Comparison between PCMs

PCM	price in kg	Density	Freezing temperature	Thermal conductivity
Water	**50.00**	**997**	**273**	**0.609**
Water-glycol 10wt%	**95.00**	**1008**	**270**	**2.18(s) 0.58(l)**
ethylene-glycol	**680.00**	**1110**	**262**	**0.258**
n-dodecane	**1300.00**	**780**	**263**	**0.134**
n-tridecane	**1570.00**	**750**	**267**	**0.131**
RT-2	**720.00**	**790**	**271.5**	**0.25(s) 0.2(l)**
RT-9HC	**-**	**880**	**263**	**0.2 (s) 0.2(l)**

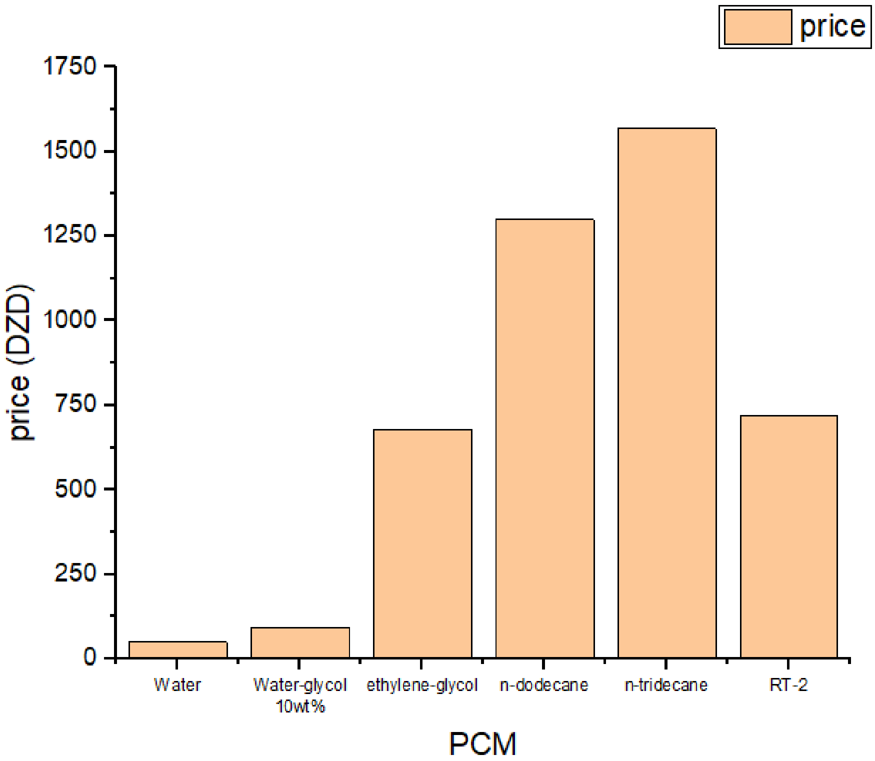

Figure 30-Price comparison between 7 PCM

Conclusion

According to obtained results, among of 7 types of PCM examined in this study, it is clear that water and Water-glycol 10wt% are the best in terms of long cold storage time. Moreover, they are less expensive compared to the rest of PCMs and have very high thermal conductivity. The later reduces considerably the freezing time and in turn the fridge power.

General conclusions

General conclusions

Refrigerators and freezers are the most common and efficient appliances preservation method. However, these devices have high contribution to household energy consumption.

The use of PCMs is probably one of the most viable alternatives in cooling systems to obtain a more energy-efficient cooling system without compromises have an environmental impact.

In this work, a mathematical study was carried out on the effect and performance of phase change materials by keeping the fridge cold for long periods.

This thesis consists of three chapters, the first chapter is a study of the literature of the principal works on this subject.

the second chapter is a theoretical study of phase change materials (PCM) and their applications, As well as general research into household refrigerators.

the final chapter also focuses on A mathematical study of the use of different kinds of phase change materials (PCM) in household fridges and choosing the best cold storage times.

Through this research, the following conclusions are drawn:

- Among seven types of PCMs used in this study, it is clear that water and water-glycol 10% are the best in terms of long cold storage time, and are very cheap compared to other PCMs, and they have very high thermal conductivity.
- When the volume of phase change equipment in the refrigerator increases, the cold hold time is longer.
- The higher of the latent heat capacity of the phase change material, the greater its cold storage efficiency.

In the end, the objective of the present work is to study the possibility of cold storage using phase change materials and to produce solar cooling in areas remote from the power grid. These materials will be incorporated directly into the structure of the vapor compression refrigerator in order to minimize the number of compressor starts at night and the reduction of battery capacity,

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Appendix

Appendix A

شرائح العملاء

الثلاجة المقترحة مخصصة للسكان الذين يعيشون في المناطق الغير متصلة بشبكة الكهرباء الوطنية، وهي مخصصة أيضا للقرى والمدن السياحية والمنازل التي تحمل العلامة "الخضراء" والتي تكون فيها مصادر الطاقة المتجددة لها الاسبقية على التقليدية، بالإضافة الى انها مخصصة للجيش الوطني المنعزلين عن المدينة والمتواجدين في الجبال والمناطق النائية وكذلك أصحاب الرحلات والتخييم، كما يمكننا استخدامه في المجال الطبي في نقل الادوية واللقاحات من منطقة الى أخرى.

عرضك / عرض القيمة

يفترض المنتج المقترح استخدام الطاقة الشمسية لتشغيل نظام تبريد ضاغط بخار تقليدي لمدة تقل عن فترة سطوع الشمس في منطقة معينة. سيتم استخدام الخزانات التي تحتوي على مادة متغيرة الطور موضوعة في المقصورتين لتخزين "باردة". سيجعل البرودة المخزنة بهذه الطريقة من الممكن الحفاظ على درجة الحرارة المحددة في المقصورتين لمدة تزيد عن 24 ساعة في هذه الحالة، تختفي الحاجة إلى تزويد النظام الكهروضوئي ببطاريات ذات سعة كبيرة. وهذا يعني أن النظام يخزن البرودة بدلاً من الكهرباء.

القنوات

تشكل قنوات التواصل والتوزيع والمبيعات حلقة الوصل بين المنشاة وعملاءها، وهذه القنوات هي واجة المنشاة التي يلمسها العملاء والتي تلعب دور في تجربة العميل، من القنوات التي تم اختيارها في الوصول الى شرائح العملاء والترويج الى المنتوج هي مزيج بين القنوات الشريكة بيع بالجملة وقنوات الخاصة عبارة فريق مبيعات وموقع الكتروني. دمجهما معا يؤدي إلى إثراء تجربة العميل وتعظيم الإيرادات حيث سيتم البيع للجملة للمتاجر مع تقديم ضمان للمنتج وسعر جيد بالإضافة الى خدمة التوصيل، اما بالنسبة للموقع الالكتروني فهو فكرة جيدة للترويج لان معظم الناس تستخدم التكنولوجيا للشراء من المواقع الالكترونية، حيث سيتم وضع جميع المعلومات وأهميته حول المنتج وطريقة استعماله والسعر وبعض الفيديوهات الترويجية للمنتج، بالنسبة للشراء سيكون الدفع عن طريق الاستلام النقدي عند استلام العميل منتجه او الدفع بالتقسيط ، من اولوياتنا راحة الزبون و توفير حاجياته من خلال التسليم المباشر لليد و التي ستكون مجانية بالإضافة الى انه تتوفر خدمة ما بعد البيع و المتضمنة في تركيب المنتج، التوجيه في كيفية استخدامه و الضمان مع الصيانة اذا حدثت مشاكل و اعطاب للمنتج.

العلاقة مع العملاء

لتوطيد العلاقة مع العملاء و توفير جميع وسائل الراحة لهم،ستكون هناك خدمتين التي تتمثل في المساعدة الشخصية حيث سيتم توفير ممثل حقيقي لقسم العلاقات مع العملاء ليحصل الزبون على جميع المساعدات اللازمة التي يحتاجها اثناء عملية الشراء او حتى بعد اتمامه سيتم هذا التواصل في الموقع او الهاتف او حتى البريد الالكتروني، اما بالنسبة للخدمة الثانية فهي خدمة الية حيث يتم وضع ملفات في الموقع للعملاء للاطلاع على الخدمات المعدة بشكل خاص لهم تتمثل في فيديوهات ،كتاب حول المنتج ،كيفية الشراء و تركيب المنتج، بعض طرق التصليح اذا حدثت اعطاب صغيرة .

مصادر الإيرادات

الطريقة التي تحقق فيها الشركة الإيرادات تكون عن طريق بيع المنتج والصيانة.

الموارد الاساسية

اهم الموارد الأساسية اللازمة لهذا المشروع يتم تصنيفها حسب طبيعتها، هناك الموارد البشرية المهندسون او خبراء رئيسيون ، كما نحتاج موارد مادية كالألواح الشمسية ومواد متغيرة الطور بالإضافة الى الثلاجات،الموارد المعنوية براءة اختراع التي تعد أساسية في المنتج وكذلك التراخيص اللازمة لإطلاق المنتج بالإضافة الى الموارد المالية لان المشروع يحتاج الى مصاريف لإطلاقه.

الأنشطة الأساسية

يتعلق هذا النشاط بتصميم وصنع وتوريد الثلاجات الشمسية المدمجة بمواد متغيرة الطور بكميات ونوعية فائقة الجودة بالإضافة الى التسويق لهذا المنتج.

هيكل التكاليف

هناك عدة تكاليف منها تكاليف الإنتاج الصيانة والموارد البشرية.

الشراكات الرئيسية

لتنفيذ هذا المشروع وانتاج هذا المنتج نحتاج الى شراكات منها الموردين لتوفير المواد اللازمة مثل الالواح الشمسية بالإضافة الى شركات التسويق وشركات التوصيل لتوصيل المنتج الى الزبون.

شرائح العملاء	العلاقات مع العملاء	القيم المقترحة	الأنشطة الرئيسة	الشراكات الرئيسية
-السكان في المناطق البعيدة عن شبكة الكهرباء **-القرى والمدن السياحية التي تحمل العلامة "الخضراء"** **-الجيش الموجودين في الجبال** **-لصحاب الرحلات والتخييم**	-مساعدة شخصية -مساعدة الية	-ثلاجة تعمل بالطاقة الشمسية مدمجة بمواد متغيرة الطور	-التصميم والتصنيع -التسويق -التوريد -الصيانة	-الموردين -شركات التسويق -شركات التوصيل
	قنوات التواصل		**الموارد الرئيسية**	
	-بيع بالجملة **-فريق مبيعات** **-متجر الكتروني**		**-العلامة التجارية** **-مهندسون وعمال** **-مواد الأولية للمنتج** **-مصاريف مالية**	

مصادر الإيرادات	هيكل التكاليف
-بيع المنتج -الصيانة	-الإنتاج -الصيانة -الموارد البشرية

Abstract

In this current era, almost every household uses at least one refrigerator to store and preserve food, as refrigerators consume a large amount of electricity due to their widespread and continuous use. Many methods have been introduced to reduce electrical energy consumption, including the use of photovoltaic systems to power conventional steam pressure refrigerators. However, photovoltaic systems require batteries with a large storage capacity to be able to operate a conventional refrigerator, a thermal photovoltaic refrigerator that integrates phase change material is one of the most attractive solutions and a new approach. phase change materials are able to store and discharge a huge amount of thermal energy by changing the phase from solid to liquid state and vice versa, as these materials are used to store thermal energy during the day when solar energy is available and release energy at night in a period of Turning off the compressor, This reduces the need for additional power sources and can help make the refrigerator more reliable in areas where electricity is unreliable or unavailable. The aim of this work is to study the possibility of cold storage using PCMs Moreover, a mathematical modeling of cold storage time was performed for seven types of PCMs of different volume.

Keywords: refrigerator, phase change material, photovoltaic energy, temperature.

الملخص

في هذا العصر الحالي، تستخدم كل أسرة تقريبًا ثلاجة واحدة على الأقل لتخزين الطعام والحفاظ عليه، حيث تستهلك الثلاجات كمية كبيرة من الكهرباء بسبب استخدامها الواسع والمستمر. تم إدخال العديد من الأساليب لتقليل استهلاك الطاقة الكهربائية من بينها استخدام الأنظمة الكهروضوئية لتشغيل ثلاجات ضغط البخار التقليدية. ومع ذلك، تتطلب الأنظمة الكهروضوئية بطاريات ذات سعة تخزين كبيرة لتتمكن من تشغيل ثلاجة تقليدية، تعد الثلاجة الكهروضوئية الحرارية التي تدمج مادة تغيير الطور من أكثر الحلول جاذبية ونهجا جديدا، مواد تغيير الطور قادرة على تخزين و تفريغ كمية هائلة من الطاقة الحرارية عن طريق تغييرها المرحلة من الحالة الصلبة الى السائلة و العكس صحيح، حيث تستخدم هذه المواد لتخزين الطاقة الحرارية اثناء النهار عندما تتوفر الطاقة الشمسية و اطلاق الطاقة في الليل في فترة إيقاف الضاغط هذا يقلل من الحاجة الى مصادر طاقة إضافية و يمكن ان يساعد في جعل الثلاجة اكثر موثوقية في المناطق التي لا يمكن فيها الاعتماد على الكهرباء او عدم توفرها. الهدف من هذا العمل هو دراسة إمكانية التخزين البارد باستخدام مواد تغيير الطور حيث تم اجراء دراسة رياضية لوقت تخزين البارد لسبع انواع من مواد تغيير الطور بأحجام مختلفة.

الكلمات المفتاحية :ثلاجة، مادة متغيرة الطور، الطاقة الكهروضوئية، درجة الحرارة.

Résumer

À l'heure actuelle, presque tous les ménages utilisent au moins un réfrigérateur pour stocker et conserver les aliments, car les réfrigérateurs consomment une grande quantité d'électricité en raison de leur utilisation généralisée et continue. De nombreuses méthodes ont été introduites pour réduire la consommation d'énergie électrique, y compris l'utilisation de systèmes photovoltaïques pour alimenter les réfrigérateurs à pression de vapeur conventionnels. Cependant, les systèmes photovoltaïques nécessitent des batteries avec une grande capacité de stockage pour pouvoir faire fonctionner un réfrigérateur conventionnel. Un réfrigérateur thermique

photovoltaïque qui intègre un matériau à changement de phase est l’une des solutions les plus attrayantes et une nouvelle approche. Les matériaux à changement de phase sont capables de stocker et de décharger une énorme quantité d’énergie thermique en changeant la phase de l’état solide à l’état liquide et vice versa, car ces matériaux sont utilisés pour stocker l’énergie thermique pendant la journée lorsque l’énergie solaire est disponible et libérer de l’énergie la nuit. Cela réduit le besoin en sources d’alimentation supplémentaires et peut aider à rendre le réfrigérateur plus fiable dans les zones où l’électricité n’est pas fiable ou indisponible. Le but de ce travail est d'étudier la possibilité de stockage de la froidure à l'aide de PCM. Plus encore, dans l’étude on y trouve exposé la méthode d’estimation du temps de stockage du froid pour sept types de PCM de volumes différents.
Mots clés : réfrigérateur, matériau à changement de phase, énergie photovoltaïque, température.