



# Effect of Phase Change Materials on Indoor Air Temperature in the Mediterranean Climate

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## Abstract

Utilizing phase change materials in buildings can increase residence satisfactory and energy saving. This study is aimed to investigate the effect of phase change materials on building indoor air temperature fluctuation under Mediterranean climate. Different types of phase change materials, encapsulation and incorporations into building fabrics methods as well as the most common simulation software are presented. Specific phase change material, called RT31, is simulated as a lining layer on all interior sides of construction elements in a duplex building with 180 m<sup>2</sup> total floor area in Energy Plus software in the summer period (June to October). Finally, it is concluded that the mean indoor air temperature was reduced by 1.8% and peaks of temperature fluctuation curve became more smooth.

**Key words:** Phase change materials (PCMs), Mediterranean climate, Building, indoor air temperature fluctuation, Energy efficiency.

## 1. Introduction

The primary energy, available in the nature, provides the world energy demand. Primary energy could be found in the form of renewable or non-renewable source such as oil, gas, coal, wind, sun and uranium. The growth in fossil fuel consumption has led on to the elevation of CO<sub>2</sub> emission and thus the global warming [1]. Two solutions are suggested to decrease the undesirable results of fossil fuel consumption. The first one is improving the energy consuming system in a way that they consume less energy and the second one is using the renewable sources to produce energy. Although the amount of produced energy from renewable sources is increased recently, they do not have a key role in the total energy production in comparison to other types of fuels. It will take a



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long time for the renewables to overcome the differences with fossil-based fuels energy sources. This weakness in the renewables resulted in raising the importance of decrease in fossil fuels consumption [2].

Electricity is the main source of energy that is used frequently for heating, cooling, lighting, air conditioning and ventilation. The total final energy use globally accounts for 7209 Mtoe (Mega Tonnes Oil Equivalents) [3]. The commercial and residential building sectors account for 638 and 1951 Mtoe respectively [3]. Buildings consume 36% of the final energy use in the world, which is the biggest share compared with others. Meanwhile, some amount of energy that has been consumed in industry section belongs to buildings. Thus, it is predicted that buildings account for almost 40% of the total end-use energy [3]. Heating and cooling systems consume the biggest part of energy in building, only HVAC equipment consumes around 15% [4].

Thermal mass keeps heat during the day when the air temperature goes up and discharges stored heat during the night when air temperature goes down. It prevents building from overheating. Phase change materials (PCMs) can provide thermal mass in building by higher heat storage capacity in comparison with conventional building materials. Heat storage capacity of PCM drywall is almost 10 times more than a regular wall [5]. This feature makes it a proper candidate to solve poor thermal comfort and overheating problem in buildings which leads to more energy consumption.

The main aim of this research is to investigate the effect of PCMs on improving thermal comfort and the building indoor air temperature fluctuation under the Mediterranean climate. The fluctuation reduction can impact the size of cooling system and consequently reduces building energy consumption in the summer period. In order to analyze building thermal performance, a thermal simulation was carried out by Energy Plus software on a duplex building with 180 square meters total floor area in the Mediterranean area.

## **2.Phase Change Materials**

All of the building materials have thermal capacity and resistant. Heat can be reserved for them either in the latent or sensible form. Thermal energy is stored by both changing the internal energy (sensible heat storage), and the phase (latent heat storage) of fabrics. Heavy fabrics are used for sensible heat storage while PCMs can be used for latent heat storage.

PCM keeps the indoor environment thermally stable by reserving more heat, achieved by storing latent heat, in comparison to other materials. When the environment temperature goes up, PCM melting is started and it turns from solid to a liquid state. This process absorbs heat and prevents environment temperature increase. When the temperature falls below the PCM melting point, solidification process is started and it turns from liquid to solid form. It is an exothermic process thus released heat increase environment temperature. These processes decrease both heating and cooling load [6].

Many researchers have proven that PCMs to be used in building application should possess some specific properties such as high latent heat and specific heat, long-term chemical stability and abundant and available [6-9].

### **2-1- Types of PCMs**



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PCMs are divided into three groups, organic, inorganic, eutectics with a different range of melting temperature and enthalpy [4].

Organic compounds are subdivided into paraffin and non-paraffin. They crystallize with little or no subcooling and are usually non-corrosive [8]. They provide wide melting temperature range; moreover, they are chemically stable and recyclable and good compatibility with others fabrics. However, they are low thermal conductive and flammable [7, 10]. Paraffins are usually cheap chemically inert PCMs. They have a moderate thermal storage density, approximately 200 KJ/Kg or 150 MJ/m<sup>3</sup>. However; they have low thermal conductivity, approximately 0.2 W/m°C, and large volume change. They do not undergo phase segregation. Their melting temperature range is between 20°C and 70°C [6, 11]. The non-paraffins can be fatty acids, esters, glycols and alcohols. They have a wide melting temperature range between 7°C and 187°C. Their heat of fusion is between 42 and 250 KJ/Kg. Fatty acids exhibit excellent freezing/melting characteristics without any supercooling. Their higher cost that is rough three times greater than paraffins is their main drawback [12].

Inorganic compounds are composed mainly of hydrated salts such as sodium sulfate decahydrate, calcium chloride hexahydrate, sodium thiosulphate pentahydrate, sodium acetate trihydrate and barium hydroxide octahydrate [12]. These materials have high heat of fusion and desirable thermal conductivity, about 0.5 W/m°C. These have high volumetric storage density, about 350 MJ/m<sup>3</sup> [11]. Low price, non-flammability and readily availability are their main advantages; however, their most problems are corrosive, subcooling, supercooling and phase segregation. Their melting temperature is about 18 to 36°C and their latent heat is between 147 and 281 KJ/Kg [13].

Eutectics are mixtures of two or more constituents that have congruent melting/freezing points. This prevents the phase segregation and makes the material more stable after melting and freezing cycles. Their volumetric storage density is slightly higher than that of organic compounds [6]. Eutectics may be divided into 3 groups according to the materials of which they consist: (I) organic-organic, (II) inorganic-inorganic and (III) inorganic-organic eutectics. Some of eutectics have the range of melting points between 18 and 51°C and freezing points between 16 and 51°C, with a heat of fusion between 120 and 160 KJ/Kg [6].

## **2-2- Incorporation of PCMs into Construction Materials**

Incorporation of PCMs within building materials is noteworthy to prevent leakage problem at least. Some incorporation methods are direct incorporation, encapsulation, shape-stabilized and immersion [10]. Many researchers investigate these methods in detail [4, 10, 14 – 17].

## **2-3- PCM Modelling Software**

PCMs phase transition elaborations and complicated such as thermo-physical materials properties changing, latent heat storage and release and unspecified temperature range for phase change lead to absolutely complex computer modelling. There are large numbers of energy simulation software can model PCMs directly and indirectly. Energy Plus, ESP-r, IES virtual environment and TRNSYS are some of them.

One of the energy simulation software which has an ability to model PCMs directly is Energy Plus. It is widely used, open source and powerful thermal simulation software. Energy Plus takes



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advantages of algorithms that able to simulate located PCMs in any position in a multilayer wall while other aspects of thermal simulation are fixed [18]. This software was simulated polyurethane foam and micro-capsulated paraffin PCM which was used in a camper van [19].

ESP-r software was used to simulate the PCMs in building directly. ESP-r is able to model PCM as result of refinement by adding the effect of phase transition [20]. It can be done in the ESP-r special materials facility that allows software to model active building fabrics.

IES virtual environment software needs additional processes to carry out PCMs modelling and simulation. In other words, IES virtual environment models PCMs indirectly. A room was modelled which has a conditioned cavity behind the PCM [21]. Melting point of PCM is set to this cavity. The conditioning is switched on when set temperature is reached and it is switched off when latent heat of PCM is dissipated. Moreover, in freezing part, the room is conditioned until release of all PCM's latent heat is done. The conditioning should be switched off or on based on its heat energy which should be recorded frequently. The biggest downside of this method is major manual intervention, which is mentioned before. The authors confined their simulations only for a hottest month, August, due to mentioned drawback [21].

TRNSYS is another energy simulation program which simulate and model PCM indirectly however it has the specific component named Type 56 which models thermally active building element. Radiant floor heating, radiant ceilings and wall cooling and heating are conditioning systems in building which involve fluid flow within them. The Type 56 can model the PCMs due to the similarity between radiative walls and PCM walls. In the melting process, thermal energy will be discharged by fluid until all of the latent heat is released when the PCM temperature reaches melting point. Conversely, energy will be stored in a wall when the PCM temperature reach freezing point until the latent heat is discharged [22].

### **3. Case Study**

In order to find the most typical Cypriot building, the last building statistical report in North Cyprus which was published by State Planning Organization was investigated in terms of type, material, floor area and number of floors. It was found that two story duplex house with 101m<sup>2</sup> to 200m<sup>2</sup> total floor area constructed with reinforced concrete and brick is a prototypical building in North Cyprus. The architectural plan of modelled building is illustrated in Figure 1 below. The walls composed of perforated clay bricks and floor were made up of marble and concrete whereas reinforced concrete slab was used as roof. The PCM lining was applied to all inner surfaces of walls and ceiling. For analyzing the effect of PCM lining, same building was modelled with the same lining, but without phase change feature.

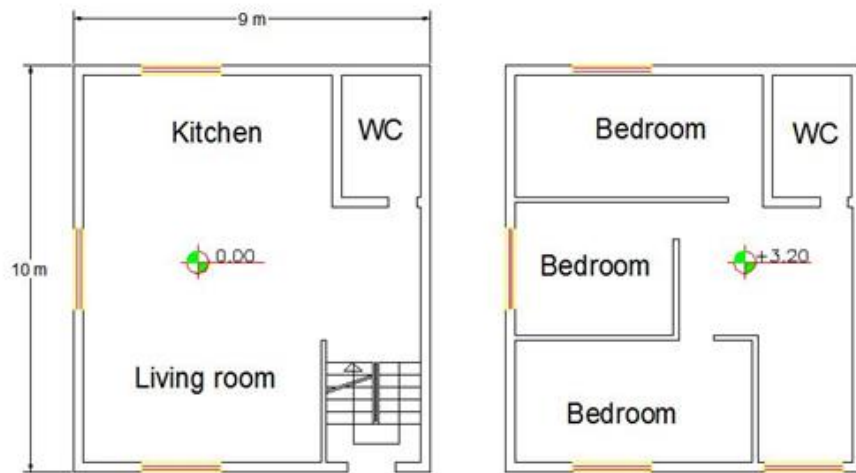


Figure 1 :Architectural plan of modelled building

Perforated clay bricks with 10cm and 20cm were respectively used in both internal and external wall construction. Inner and outer surfaces of external walls were covered by 4cm of lining (PCM) layer and 2.5cm of cement plaster respectively; meanwhile, both surfaces of internal walls were covered by 4cm of lining (PCM). Generally, both sides of walls are painted by white color in Cyprus. Although paint layer has negligible thermal resistance, solar and thermal absorptances of white color have a noteworthy effect on heat gain via short wave radiation thus these values were considered for surface properties of walls. Thermal properties of different wall layers are given in Table 1 below.

Table 1: Wall layers' thermal properties

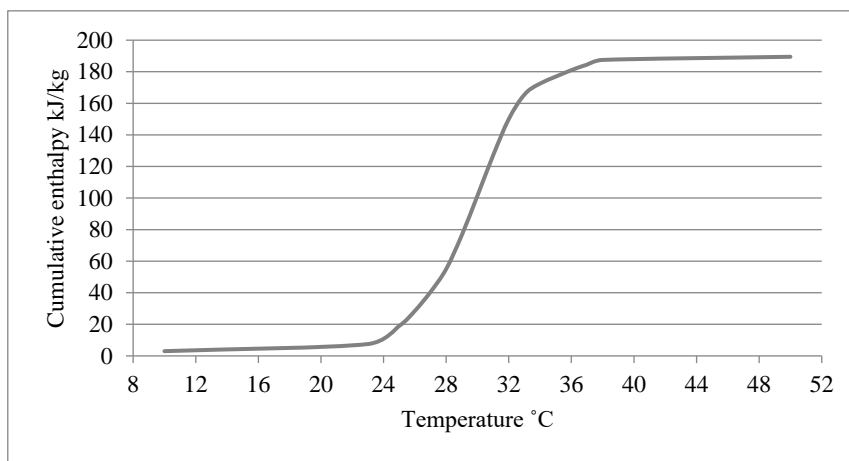
Layers	Plaster	Perforated clay brick	Lining
Roughness	M. smooth	M. rough	M. smooth
K (W/m k)	1.4	0.4	0.2
d (kg/m <sup>3</sup> )	2000	700	820
C <sub>p</sub> (J/kg k)	650	840	2000
Thermal	0.9	0.9	0.9
Solar	0.26	0.63	0.26
Visible	0.1	0.7	0.1

Grade level floor was made up of five layers. The top layer was marble with 3cm thickness after that 2cm of screed was used for the second layer. Underneath the screed, 5cm sand layer was applied. In the next layer, 10cm concrete was employed. Finally, at the bottom, 15 cm hard-core layer standing on the compressed earth with coarse gravel was used. Meanwhile, first level floor was composed of four layers. A 3cm marble was the upper layer. Screed layer with 2cm thickness was placed under the marble layer meanwhile, it was on the reinforced concrete with 15cm thickness. The downside of reinforced concrete was coated with 3cm lining layer. Roof was constructed with a 15cm reinforced concrete slab and its inner side was coated with 3cm lining layer. Thermal properties of different layers of floor and roof are illustrated in Table 2.

**Table 2: Floor and roof layers' thermal properties**

Layers	Marble	Screed	Sand	Concrete	Hardcore	Reinforced concrete	Lining
Roughness	Smooth	Rough	M. rough	Rough	V. rough	Rough	M. smooth
K (W/m k)	2.9	1.4	0.7	1.74	0.7	2.1	0.2
d (kg/m <sup>3</sup> )	2750	2000	1800	2200	1800	2400	820
C <sub>p</sub> (J/kg k)	840	650	840	840	840	840	2000
Thermal	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Solar	0.5	0.7	0.7	0.7	0.7	0.7	0.26
Visible	0.7	0.7	0.7	0.7	0.7	0.7	0.1

Less than ten companies produce PCMs for building application around the world. RUBITHERM® Technologies GmbH is one of the principal PCM suppliers worldwide [23]. RT 31 was selected for the current study due to its melting temperature and heat storage capacity. Melting temperature of PCM, for cooling application in building, should be around the average temperature of the summer months [4]. For simulation with Energy Plus, temperature and corresponding enthalpy value are needed. The amounts of enthalpy for a range of temperature are given by producer. The enthalpy–temperature values should cover all the temperatures seen by the materials in Energy Plus. Based on the Cyprus weather condition, these values should be in the range of 10°C to 50°C. A linear line can be fitted to first and last values. Thus, the cumulative temperature-enthalpy is drawn in Figure 2 below.



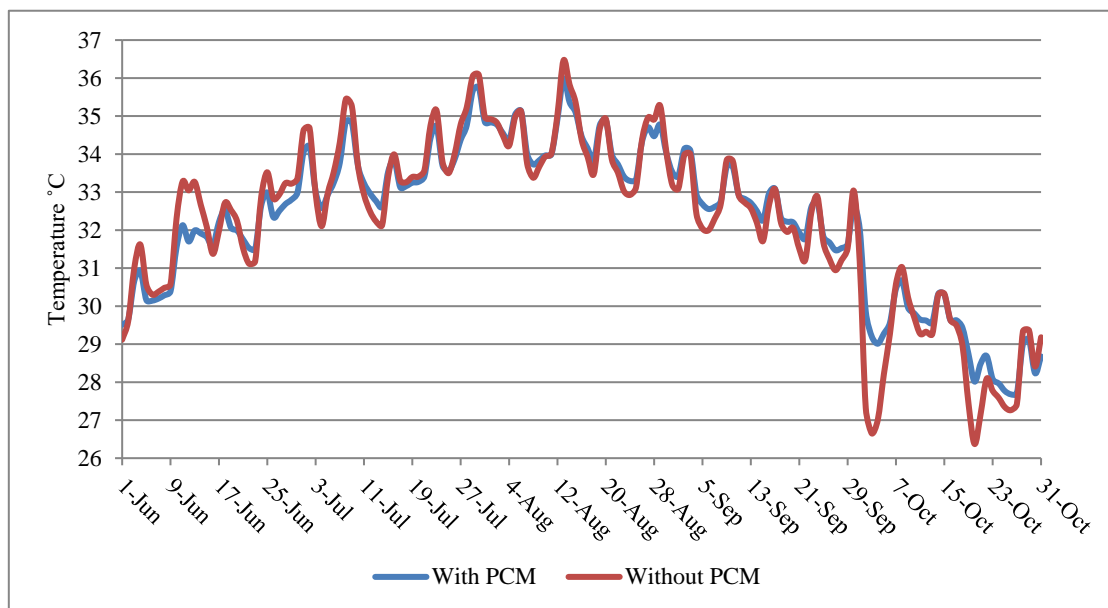
**Figure 2 :Cumulative enthalpy-temperature curve**

It was assumed that the modelled building was unoccupied in weekdays from 7:00 to 18:00 because it is a residential building and in any other hours, it is occupied. Moreover, with regard to the people social life, working hours were assumed from 8:00 to 17:00. Furthermore, as the simulation period was defined from June to October, the artificial lighting is needed after 18:00 inside the building. The electric equipment schedule is different on weekdays and weekend because of a difference in residence occupancy. It was assumed that the electric equipment is used from 6:00 to 7:00 and after 18:00 in weekdays and after 8:00 in the weekends. In order to consider the human heat gain, it should be noted that the total heat gain from each person is changed in different situations. Each

person releases 72 W and 126 W in sleeping and doing activity respectively [24]. Thus, three values were considered for this schedule; 0 watt per person for unoccupied condition, 72 watts per person in sleeping time and 126 watts per person in other conditions.

#### 4. Results and Discussion

The case study building was modelled in Energy Plus and a dynamic thermal simulation was carried out to calculate indoor air temperature. Daily mean indoor air temperature in two cases (with and without PCM) for summer months (June to October) are illustrated in Figure 3. As these two cases were completely same except the phase change ability in lining (PCM) layer which was applied in “With PCM” case. With regard to the indoor air temperature, PCM decreased the temperature fluctuation by temperature peak reduction. The maximum peak reduction was happened on 12<sup>th</sup> June when indoor temperature was reduced by 4.24%; meanwhile, on 3<sup>rd</sup> October the indoor temperature was increased by 8.73%.



**Figure 3 : Daily mean indoor air temperature**

The maximum daily indoor air temperature reduction in June is occurred on 12<sup>th</sup> by 1.34°C when the phase change ability of lining (PCM) layer is active. Meanwhile, the minimum daily indoor air temperature reduction is happened on 6<sup>th</sup> by 0.16°C. Forasmuch as daily indoor air temperature have a good fluctuation around phase change temperature (31°C), the PCM works properly in with PCM condition and peak reduction is significantly observed in June. In the next month, the maximum daily indoor air temperature reduction is turned out on the 8<sup>th</sup> by 0.6°C in with PCM condition. Although the daily indoor air temperature is more than phase change temperature in July, the daily indoor air temperature peak is negligibly slumped. The indoor air temperature is always more than the phase change temperature in August and therefore, PCM cannot be active. In other words, PCM is kept in the liquid phase and the absorbed heat is not able to release to the environment thus peak reduction and temperature fluctuation decrease is not significant in this



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month. In September, daily indoor air temperature is gently dropped from 34°C to 31°C and maximum of daily indoor air temperature peak is declined by 0.65°C on 5<sup>th</sup> September. Finally, in October, maximum daily indoor air temperature peak reduction is occurred on 3<sup>rd</sup> by 2.55°C when the phase change ability of lining layer is active.

With regard to the daily indoor air temperature in the period of June to October in both mentioned cases, the temperature fluctuation is reduced in all days. Although it has a gradual decline in July and September, it sharply drops in June and October. In contrast, the daily indoor air temperature is not considerable affected by application of PCM in August, in other words, temperature fluctuation reduction has a slight trend in this month.

## **5. Conclusion**

To investigate the effect of PCM on indoor air temperature fluctuation, a dynamic simulation was carried out by help of Energy Plus software and the results were studied in term of daily indoor air temperature in the period of June to October. It was found that, the lining layers affected the daily indoor air temperature by peak reduction. Although this effect was not considerable in August, the peak reduction in other months had a steep trend especially in June and October. As it was mentioned before, the PCMs absorbed the heat during the charging process and released the heat during discharging process. In other words, PCM try to smooth the indoor air temperature fluctuations and consequently the size of a required cooling system will be decreased which can positively effects the building energy consumption. As a result of the dynamic thermal simulation, it can be seen that the highest value of maximum hourly indoor air temperature decrease was around 2.4°C occurring in June due to sufficient indoor air temperature fluctuation around phase change temperature when the phase change ability was not applied. In the meantime, the highest value of minimum hourly indoor air temperature increase was almost 3.5 °C happening in October when the indoor air temperature had an enormous reduction in a week. Finally, it can be concluded that application of PCM in building under the Mediterranean climate can be a potential method to stable the indoor air temperature in a fix temperature and therefore enhance the cooling devices performance; however, the authors believe that combination of different PCMs with various melting temperatures can increase its performance to control the indoor air temperature fluctuations and to decrease the cooling system size.

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