YAŞAR UNIVERSITY
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MASTER THESIS

ENERGY PERFORMANCE EVALUATION FOR FACADE DESIGN WITH PCM IN HOT-DRY AND COLD-HUMID CLIMATIC REGIONS

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We certify that, as the jury, we have read this thesis and that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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ABSTRACT

ENERGY PERFORMANCE EVALUATION FOR FACADE DESIGN WITH PCM IN HOT-DRY AND COLD-HUMID CLIMATIC REGIONS

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In recent years, numerous scholars' efforts are being made to reduce the impacts of climate change all over the world. The buildings where people spend most of their time have a reciprocal influence on climate change in the terms of energy consumption. In other words, while climate change affects human behavior in the buildings, their behavior changes have a key impact on the climate change. Therefore, various methods have been explored to optimize the energy use intensity (EUI) in the buildings. As exploring solutions to address excess energy use intensity, an intense increment of the use of glazing structure has been observed recently. This increasing trend of using the glazing facade results in a rise to energy use intensity besides affecting indoor temperature. However, usage of Phase Change Material (PCM) systems in the buildings with thermal storage capability has been reached between the measures that can be taken against climate change. Considering the Phase Change Material system's impacts on the mitigation of energy consumption, this study represents an investigation for the working principle of the glass structure with Phase Change Material. This thesis aims to evaluate the comparison of energy gains and losses in a test room as the living room in a building modeled for various envelope systems with an integrated glass structured envelope system. It examines the performances of the greenhouse structure integrated to the south façade of the building and the Phase Change Material used for thermal storage. Thermal performances of these facade systems were investigated for Luxor (Egypt) and Erzurum (Turkey), which respectively for hot-dry and cold-humid climatic regions in the energy simulation engine DesignBuilder. The main objective of this study is to investigate the indoor air temperature and energy consumption amounts for 2 different climatic regions by assuming the building model is located in Luxor and Erzurum and to designate the most appropriate design alternatives for both climatic regions.

Key Words: glass structured envelope, thermal performance, building energy performance simulation, DesignBuilder, phase change material (PCM)

ÖZ

SICAK-KURU VE SOĞUK-NEMLİ İKLİM BÖLGELERİNDE PCM İLE CEPHE TASARIMI İÇİN ENERJİ PERFORMANS DEĞERLENDİRMESİ

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Günümüzde, tüm dünya iklim değişikliklerine ve iklim değişiminden kaynaklı etkilere maruz kalmaktadır. İnsanların zamanının çoğunu harcadıkları binalar da özellikle enerji tüketimi olmak üzere birçok konuda bu değişikliklerden etkilenmektedir. Başka bir ifadeyle, iklim değişikliği binalardaki insan davranışlarını etkilerken, onların davranış değişikliklerinin de iklim değişikliği üzerinde önemli bir etkisi vardır. Sonuç olarak, binalarda enerji kullanımı yoğunluğunu (EUI) optimize etmek için çeşitli yöntemler araştırılmaktadır. Son yıllarda, yapılmış yapılarda cam konstrüksiyon kullanımının yoğun olduğu gözlenmiştir. Cam cephe kullanımındaki artan yoğunluk, iç hava sıcaklığını etkileyerek enerji kullanımı oranının artmasına sebep olmaktadır. Yapılan araştırmalara göre, iklim değişikliğine karşı alınabilecek önlemler arasında termal depolama özelliğine sahip faz değiştiren malzeme sistemlerinin binalarda kullanımına ulaşılmıştır. Faz değiştiren malzeme sistemlerinin enerji tüketimini azaltmaya yönelik etkileri düşünüldüğünde, bu çalışma, faz değişim malzemesi materyalinin cam ile birlikte kullanımının araştırılmasına yöneliktir. Bu tez, güney cephesine entegre edilmiş cam sistemine sahip bir binadaki enerji kazanç ve kayıplarını analiz etmeyi ve karşılaştırmayı amaçlamaktadır. Binaya entegre edilmiş sera yapısının ve termal depolama malzemesi olarak adlandırılan faz değişim malzemesinin performansını incelemektedir. Yapılan çalışmada, sıcak-kuru ve soğuk-nemli iklim tiplerine sahip Luxor (Mısır) ve Erzurum (Türkiye) kentlerindeki termal performanslar enerji simülasyon motoru (DesignBuilder) ile incelenmiştir. Bu çalışmanın amacı, bir bina modelinin Luxor ve Erzurum'da yer aldığı varsayılarak iki farklı iklim bölgesinde iç mekân hava sıcaklığı ve enerji tüketimi üzerine davranış farklılıklarının incelenmesi ve en uygun tasarım alternatiflerinin belirlenmesi için simülasyon modeli geliştirilmesidir.

Anahtar Kelimeler: cam yapıya sahip zarf, termal performans, bina enerji performans simülasyonu, DesignBuilder, faz değiştiren malzeme (FDM)

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I would like to express my enduring love to my parents Yasemin-Bahri Ekim and my siblings İrem Buket Ekim and Eren Ekim, who are always supportive, loving, helpful and caring to me in every conceivable way in my life. Lastly, there are tinier but same age exactly after these health problems, they entered in my life; my 4-foot mischievous. It's a good thing you have entered in my life...

Hüma Fulya EKİM
İzmir, 2020

TEXT OF OATH

I declare and honestly confirm that my study, titled “ENERGY PERFORMANCE EVALUATION FOR FACADE DESIGN WITH PCM IN HOT-DRY AND COLD-HUMID CLIMATIC REGIONS” and presented as a Master’s Thesis, has been written without applying to any assistance inconsistent with scientific ethics and traditions. I declare, to the best of my knowledge and belief, that all content and ideas drawn directly or indirectly from external sources are indicated in the text and listed in the list of references.

Hüma Fulya EKİM
Signature
………………………………..

July 8, 2020

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SYMBOLS AND ABBREVIATIONS

ABBREVIATIONS:

CFD	Computational Fluid Dynamics
EUI	Energy Use Intensity
GR	Granulate
HTF	Heat Transfer Fluid
HVAC	Heating, Ventilation and Air-Conditioning
IPCC	Intergovernmental Panel on Climate Change
m	Meter
mm	Millimeter
PCM	Phase Change Material
PCWW	Passive Cooling Water Wall
PV	Photovoltaic
RT	Rubitherm
TES	Thermal Energy Storage

SYMBOLS:

^{o}	Angle Degree
A	Area (m^2)
°C	Centigrade Degree
ρ	Density (kg/m^3)
T_{in}	Indoor Temperature in °C
T_{inter}	Inter-space Temperature in °C
T_{out}	Outdoor Temperature in °C
%	Percentage
c	Specific Heat / Thermal Capacity (J/ (kg. K))

λ	Thermal Conductivity (W/ (m. K))
U	Thermal Transmittance (W/ (m^2. K))
d	Thickness (m)

CHAPTER 1
INTRODUCTION

The earth is experiencing global climate changes caused by global warming. The world has been exerting effort to mitigate the climate changes nowadays and the scholars are therefore figuring out various methods to optimize the energy use intensity (EUI) for the built environments. The climate's impact on the energy consumption of the built environment is an undoubted fact that is crucially effective on the habitant's lifestyle in the cities while changing their habits on the consuming energy. This thesis requests to investigate the commonly used techniques of systems that are also effective in reducing energy consumption. Many of the studies that have developed the known techniques or applications. As a direct result of what is required, there was a demand for many researches work before developing the work presented here. The buildings where people have spent most of their time are affected by these changes and influence the energy consumption. In recent years, the use of glass construction has been observed increasing in the structures. These possibilities include glass structure and phase change material (PCM); materials will be examined as compared and their use together will be interpreted. The aim of this chapter is to enter the problem, to define the main pillars of the research, to express research questions and to define the outlines of the research.

Firstly, the type of structure will be explained briefly, then the type of building together with the work related to the building will be discussed.

1.1. Context

This thesis focuses on glass structure integrated building and consideration of the thermal performance of different climatic region's model options with and without phase change material (PCM). The glass structures used in the buildings are made from commence with the aims and application samples. The study conducted on the PCM with the studies carried out on the glass structures has been presented.

This thesis includes 7 chapters in total which starts with the introduction chapter that represents the thesis context, problem statements, research questions, aims and objectives and the thesis research method. Second chapter displays the literature review of the research gap, the existing methods. These subtitles are water wall, Trombe wall, double skin facade, greenhouse system, PCM and attached greenhouse system. Third chapter explains the passive solar heating systems. Fourth chapter focuses on expressing studies about the PCM. These subtitles are what is PCM, working principle of PCM, PCM types and examples of structures with PCM. Fifth chapter explains the methodology, four phases of the study are expressed in the different sections. These phases are base model, location and climate, design alternatives and boundaries.

In sixth chapter the Results and Discussion part demonstrates the results of the simulations. Performance of the types is evaluated in regard to different outputs in this chapter. It refers model alternatives, simulations, inputs outputs and settings. Discussion section is at the end of each section. A separate section has not been opened for the discussion section, instead of the end of each episode. Finally, seventh chapter describes the outputs, improvement and progress of the work of study.

1.2. Statement of The Problem

The increment of the glazing facade systems on the building envelope is one of the key reasons for increasing the use of unnecessary building operation systems i.e. HVAC. These systems consume lots of energy. There is an increase in urban construction sites and energy-consuming devices such as air conditioning, so it will further increase energy consumption due to improvement in living standards and rapid urbanization. As a consequence of these processes, the energy consumption utilization rises up to set a proper temperature and air quality for indoor environments. Considering the building envelope design’s impacts on the energy utilization, this thesis addresses to discover an alternative approach (i.e. PCM) instead of glazing facade.

1.3. Research Questions

One of the leading results of the climate change is the increase in the energy consumption amount to provide thermal comfort. PCM is used for phase change structure and thus, the energy efficiency and comfortable environment are carried out in the building. With the assist of calculation material analysis, thermal and visual comfort factors of the structure will be discussed in accordance with climates and standards. In addition to the PCM's orientation in the building design steps, the annual energy use of alternatives varies in the selection of materials. In this context, the following questions are enquired about the calculation of the simulation model.

- How much energy reduction is possible by using PCM in building designs?
- Which climate type (i.e. hot-dry "like Luxor (Egypt)", cold "like Erzurum") is the most proper one for PCM usage to reduce excess energy consumption?
- Which construction PCM layering has a more impact on which climate?

1.4. Research Aim and Objectives

Research aim is to develop an envelope design model for both winter and summer time. Thus, this model is expected to be beneficial to support design decision process by exploring appropriate design alternatives. As a result of this, we aimed to recommend an integrated façade design in a building. Design types were compared to daylight and energy performance (solar gain). The research objective consists of glass structure as double glazing or glass structure integrated to water wall, Trombe wall and greenhouse structure; attached greenhouse with PCM.

Research objectives are:

- To define and to analyze the building envelope design strategies by reviewing literature
- To evaluate the energy performance of the various facade alternatives via a performance analysis tool (i.e. DesignBuilder)
- To figure out the most appropriate design strategies for 2 different climatic regions via comparing the simulation results.

1.5. Method of The Research

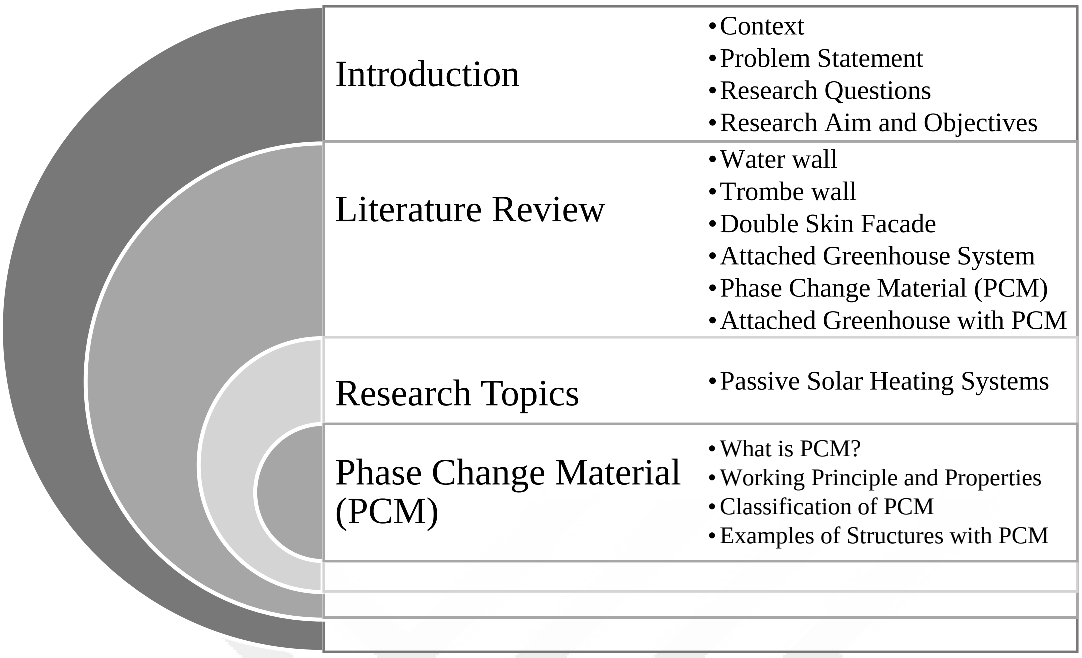


***Figure 1** Method of the Research*

The phases of the research done are as shown **in Figure 1**. This thesis is based on evaluating the energy performance of different configurations of the system in the PCM is compared present and does not exist; design alternatives that in comparison with hot-dry and cold-humid climates. Simulations will be produced to understand potential consequences (indoor temperature and daylight usage) of PCM's integration into a building located in selected locations using DesignBuilder program and with help of EnergyPlus. This has been done through developing a model for a space and assessing the performance across a year. Two weather conditions have been chosen to evaluate the performance of those wall configurations which are Luxor (Egypt) as a hot and dry climatic region and Erzurum (Turkey) as a cold and humid climatic region.

CHAPTER 2

LITERATURE REVIEW

The world is experiencing climate changes caused by global warming and this is called the global climate change. According to Yau and Hasbi (2013), nearly a decade ago, global warming and intense weather conditions considered only a hypothesis, are recognized as pioneers of changes in the global climate (Yau & Hasbi, 2013). When climate changes caused by global warming are observed over a longer period, it is possible that they can cause much greater changes. Consequently, global warming and climate change caused by global warming are the greatest threats to life on the Earth.

These climate changes will furthermore affect the construction sector. With global warming, buildings will request more cooling and less heating. Thus, the building energy consumption and carbon emissions are expected to increase. In addition to these, irregular weather events moreover affect the efficiency and sustainability of the building, thermal comfort and indoor air quality.

According to Intergovernmental Panel on Climate Change (IPCC) WG (working group)II Fourth Assessment Report *"Climate change"* usage refers to any change in climate over time, whether due to natural variability or as a result of human activity. Moreover, IPCC reported that the 40% of global energy consumption rely on the construction sector while causing the 25% of global CO_2 emissions (Metz et al., 2007). In addition, approximately 40% of greenhouse gas emissions are attributed to energy consumption in buildings (Ahmed Gassar & Yun, 2017). According to Prieto et al. (2017), the buildings are responsible for 40-45% of the total energy demand in Europe besides play a key role considering the impacts of other sectors on the energy consumption for worldwide (Prieto et al., 2017). Since Steemers (2003) has reported that buildings head for 36% of energy consumption in the United States, 41% in Europe and about 50% in the United Kingdom (Steemers, 2003). Huang and Gurney (2016) pointed out the commercial and residential buildings are responsible for 41% of primary energy consumption in 2010 for USA while 50% of the total energy consumption is caused by heating and cooling for the residential buildings (Huang &

Gurney, 2016; U.S. Department of Energy, 2011). According to Tabesh and Sertyesilisik (2016); Sümer Haydaraslan and Yaşar (2018), energy consumption varies depending on climate, location, building construction characteristics, HVAC and lighting installations, building operation and maintenance, usage and type of office equipment, user activities and behavior, working programs and ensuring indoor quality (etc.) (Tabesh & Sertyesilisik, 2016; Sümer Haydaraslan & Yaşar, 2018). The majority of the energy needs in buildings are due to the heating, cooling and ventilation needs required to provide indoor thermal comfort to the residents of the building (International Energy Agency (IEA), 2016). The most energy-efficient system of between building facilities are heating, ventilation and air conditioning (HVAC) systems (Soussi et al., 2013).

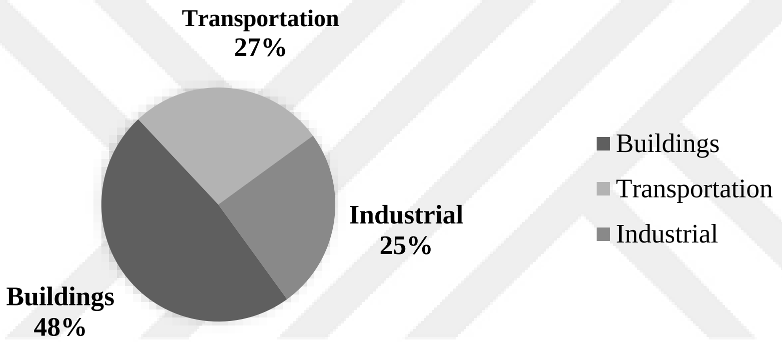


***Figure 2** Distributions on energy consumption in U (Lechner, 2015)*

48% of the whole energy consumption in U.S. belongs to the buildings where 40% for their operation and 8% for their construction as seen **in Fig. 2** (Lechner, 2015).

The energy consumption phenomena gradually increase in all over the world unless taking precautions to mitigate the redundant consumption. Considering the significance of built environment impact on these phenomena, the construction industry and the scholars highlights the potential of efficiency studies of the built environment to handle the energy deficit. Çapık et al. (2012) reported that the energy demand in Turkey has increased by approximately 8% per year owing to growths in emerging economies and rapidly increasing population (Çapık et al., 2012). As a consequence of rapidly growing populations and changing economic strategies, the overall predictions indicate that energy demand will expand by 34% in the period of 2014 and 2035 (OECD Green Growth Studies Energy Outlook, 2011). Considering the reduction studies for energy consumption, the focus of this study is the facade design intervention. The facade design is aimed by using solar energy and creating thermal mass. It is aimed to provide the following with these design interventions; reduce energy consumption and provide comfort environment. To scope down the energy efficient facade design applications, the following sections will provide a background about ‘water wall’, ‘Trombe wall’ , ‘double skin facade’, ‘greenhouse’ and ‘phase change material (PCM)’ studies in the literature.

2.1. Water Wall

Figure 3 *Solar Components Water Wall (Bainbridge, 1981)*

Water wall is a type of passive solar wall heating system that consists of thermal mass and water **in Fig. 3.** Six studies have been examined in relation to water wall in this section. These are mostly examining the theoretical and experimental studies on theory. Three of these studies do not have any climate data and simulation tool has not been specified as the following:

L. Xu et al. (2019) worked on an experimental study about seven groups with the industrial-scale experiments of combustion adjustment to conduct the influences of different operating conditions on the high-temperature corrosion, NO_x (nitrogen oxides) emission and boiler efficiency. The studied location has not been stated. This method of combustion adjustment was adopted for mitigation the reducing atmosphere near the water wall in their study (L. Xu et al., 2019). However, the location has been indicated for other two of them. H. Xu et al. (2019)’s study represented an experimental and theoretical study in Italy about traditional and PCM-based water wall systems. They used PCMs-based bricks in the PCM-based water wall to investigate their thermal performance. Their study is presented in the combustion chamber water wall featuring PCM-based refractory brick to upgrade the thermodynamic efficiency of the energy conversion on the water wall (H. Xu et al., 2019). The last study reviewed is Bainbridge's book *"A Water Wall Solar Design Manual" (1981)* which includes several study references to represent an overall perspective about water wall. As the book mentioned, the first water wall was built in 1947 at Massachusetts Institute of Technology (MIT) and the space heating was provided in the range of 38-48% by those walls. Another instance is the school building in Mexico which has a large water tank. The water storage has been supplying drinking water for who lived in the school such as teachers and students. The only buildings have been reportedly were that they are very comfortable (Bainbridge, 1981).

Venkiteswaran et al. (2017) made a theoretical study for an educational building on tropical climate in Kuala Lumpur, Malaysia. They used the package program called ANSYS FLUENT for this study and compared the thermal performances of the system via CFD (Computational fluid dynamics) analysis. Passive cooling water wall (PCWW) was developed to cool the glass facade of this building as passive cooling system and thus reduce the heat penetrating the building on the 14th floor in SEGi University Tower. The PCWW system, which is included in the building could be saved a total of 658.972 kWh per month. As a conclusion, the PCWW is a simple and cost-effective method for reducing building indoor temperature and saving energy (Venkiteswaran et al., 2017).

The other two samples are about China's climate; Wang et al. (2013) have studied on passive solar home (PSH) for temperate climate in Tianjin, North China. The effect of the water thermal storage wall (WTSW) on indoor thermal environment has been analyzed via TRNSYS tool. It was used to simulate the variation of indoor temperature, energy performance and thermal comfort. The results of the simulation and the analysis demonstrate that compared to traditional wall the PSH equipped with WTSW can reduce annual energy consumption by 8.6% and improve indoor thermal comfort evaluation index by 12.9% (Wang et al., 2013). The last sample is Lui and Feng's (2013) work that is an experimental study about two test rooms of multi-purpose building in humid subtropical climate of Shenzhen, South China. In this study, indoor discomfort hours were decrease more than 30% by passive cooling system and passive solar techniques have been reduce 25% annual heating loads. The combination of passive cooling and passive solar techniques has shown that significant effects can be achieved to reduce energy consumption by internal comfort by improving existing buildings in South China (Lui & Feng, 2013).

These six studies examined the water wall advantages and the usage for different reasons, the studies examined the performance of the water walls by the assistance of computational tools (such as TRNSYS and ANSYS FLUENT) **in Table 1.** Thermal performance has been analyzed and it was found to contribute to ensure indoor thermal comfort and reduce energy consumption. It is argued that the sustainable technologies can be designed together to create a more efficient system.

Table 1 Literature Review about Water Wall

Year	Author(s)	Source Title	Studied Location	Climate Type	Building Type	Material Type	Simulation Tool	Simulation Type	Study Type
2019	L. Xu, Y. Huang, L. Zou, J. Yue, J. Wang, C. Liu, L. Liu, L. Dong	Experimental research of mitigation strategy for high-temperature corrosion of water wall fireside in a 630 MWe tangentially fired utility boiler based on combustion adjustments	Not directly stated	No climate data	No building type is mentioned.	No material type is mentioned.	No simulation program is mentioned.	No simulation type is mentioned.	experimental study
2019	H. Xu, W.Y. Lin, F. Dal Magro, T. Li, X. Py, A. Romagnoli	Towards higher energy efficiency in future waste-to-energy plants with novel latent heat storage-based thermal buffer system	Italy	No climate data	PCMs-based bricks in water wall (traditional and PCM-based)	three types of PCMs-based bricks	No simulation program is mentioned.	thermal performance	experimental & theoretical study
2017	V. Kumar Venkiteswaran, Wong Dee Lern, Surenthira Stephen Ramachanderan	A Case Study on the Use of Harvested Rainwater to Operate Passive Cooling Water Wall (PCWW) for SEGi University Tower	Kuala Lumpur, Malaysia	tropical	classrooms with and without PCWW (Passive Cooling Water Wall) system	concrete, glass, water, air	ANSYS FLUENT	thermal performance, CFD analysis	theoretical study
2013	Y. W. Liu, W. Feng	Integrating passive cooling and solar techniques into the existing building in South China	Shenzhen, South China	Humid subtropical	two test rooms in multi-purpose building	sun space: wood pine(grain), air gap, plaster board; Trombe wall: insulation material?, glass, vacuum insulating, air gap, asphalt, brick kaolin insulating; water wall: glass, vacuum insulating, glass, air gap, polyvinylidene fluoride(kynar), water	Ecotect, SolPass software	CFD analysis	experimental study
2013	W. Wang, Z. Tian, Y. Ding	Investigation on the influencing factors of energy consumption and thermal comfort for a passive solar house with water thermal storage wall	Tianjin, North China	Not directly stated	passive solar house	WTSW(water thermal storage wall) outer wall made of steel plate, steel construction and gypsum boards,	TRNSYS	Indoor temperature, energy performance, thermal comfort	experimental study
1981	D. A. Bainbridge	Chapter 2: A Capsule History of Water Wall Solar Buildings	Mexico	No climate data	many types of building	a large water tank	No simulation program is mentioned.	thermal performance	No study type is mentioned.

2.2. Trombe Wall

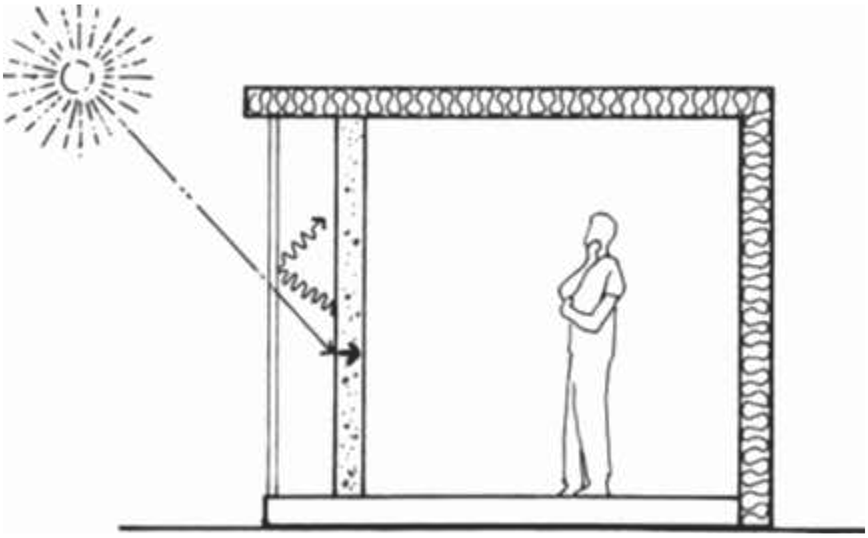


Figure 4 *Trombe wall (Lechner, 2015)*

Trombe wall is a type of passive solar wall heating system that consists of thermal mass (the wall is made of an effective material that absorbs solar radiation) and window or glass wall **in Fig. 4.** In this section, ten studies have been examined related to the Trombe wall system that all of them are experimental studies.

Two of the studies do not specify climate data and studied locations that are experimental and theoretical studies as following: Lamnatou et al. (2020) and Lamberg et al. (2004). Lamnatou et al. (2020) have studied an overview of storage systems that are appropriate for building-integrated photovoltaic (BIPV) and building-integrated photovoltaic/thermal (BIPVT) applications. They have been used to produce clean energy and to replace conventional building envelope materials. In this article is regarding PCMs, some materials are corrosive and present fire-safety issues as well as high toxicity in terms of human health and ecosystems. Additional storage options such as Trombe walls, pebbles and nanotechnologies are critically discussed. The contribution of the present article to the existing literature is associated with a critical review about storage devices in the case of BIPV and BIPVT applications, by emphasizing the environmental profile of certain storage materials (Lamnatou et al., 2020). Lamberg et al. (2004) have studied in two distinct kinds (with and without heat transfer enhancement structures) of PCM storage wall and it was designed and constructed using with FEMLAB simulation software operates in the MATLAB. The enthalpy and the effective heat capacity methods have given good estimations for the temperature distribution of the storages in both the melting and freezing processes in the numerical methods in the numerical methods (Lamberg et al., 2004).

Three of the studies have been studied for the Mediterranean climate. Kurnuç Çırakman (2010) studied an experimental study about the annual performance of the wall containing PCM of the southern wall, considering the design of a new generation of Trombe wall (or briefly PCM wall) that stores solar energy in latent heat. The structure of the PCM wall consists of insulation, brick, PCM-joined plaster, air gap, and specially designed transparent insulation unit. The PCM wall has been examined for 15 months from October 2008 until the end of December 2009, and after evaluations have been linked to the results. The overall yield of the wall containing GR35 PCM has been larger than the overall efficiency of the wall containing GR41 PCM. From here, the overall efficiency has been reduced as the phase change temperature increases (Kurnuç Çırakman, 2010). Kundakcı Koyunbaba et al. (2013)’s study is based on the experimental and theoretical study on a model BIPV Trombe wall built in Izmir, Turkey. Computational fluid dynamics (CFD) were used to estimate the indoor temperature and air velocity distribution in the test room model. According to the simulation results, the PV module and thermal wall are in good agreement with the measured hypothetical data. The average electrical and thermal efficiency of this system can reach experimental daily with 4.52% and 27.2% respectively (Kundakcı Koyunbaba et al., 2013).

Jaber and Ajib (2011) have worked on studying the Trombe wall system for a residential building in Amman, Jordan. This wall system has significant advantages such as both reductions in fuel consumption and auxiliary energy system size in the Mediterranean region. That is because the Trombe wall system depends on the availability of solar radiation; when there is high solar radiation, less heating demand is required or vice versa (Jaber & Ajib, 2011). Rabani and Rabani (2019) have studied experimental study on heating performance enhancement of an innovative design Trombe wall using rectangular thermal fin (aluminum, brass and copper fins) arrays at the experimental test room in the arid climate of Yazd, Iran. The results demonstrated that when the thermal fin is used, the performance efficiency of the Trombe wall increases up to 3% in terms of stored energy within the Trombe wall and 6% in terms of natural convection heat transfer rate inside the channel (Rabani & Rabani, 2019).

Soussi et al. (2013) have studied experimental and theoretical study on laboratory building, a solar cooled office building built with a bioclimatic design in Borj Cedria, Tunisia. The laboratory building was used to analyze the effects of passive techniques is suggested to avoid overheating during the summer to achieving a higher comfort in the building. Moreover, the study will be focused on analyzing the efficiency of the storage walls implemented in the building, three extreme scenarios are shown: building with storage walls; building with storage walls and solar overhangs; and building without storage walls (Soussi et al., 2013).

Three of the studies have been studied in China. Two of them have the same authors and the same location. N. Zhu et al. and Shanshan Li et al. (2019) have studied experimental and theoretical study for the climate of Wuhan, China. In their studies, they have studied on PCM Trombe wall rooms with and without reference Trombe wall room (Zhu et al. and Li et al., 2019). For both of the studies, the material structure of the Trombe wall consists of plaster, concrete, insulation, glass, PCM used and thermal performance was examined using TRNSYS software. According to the results have been obtained by Li et al. (2019), the PCM Trombe wall showed that an increase in indoor overheating during the summer and decrease indoor temperature change in winter. Based on these, the PCM Trombe wall can increase indoor thermal comfort and reduce the cooling/heating load in the whole year compared with the traditional Trombe wall (Li et al., 2019). Zhu et al. examined the novel Trombe building model integrated with double layers PCM wallboard on the south wall, while, W. Li and W. Chen (2019) have studied experimental study about two test rooms of a multi-purpose building in local weather station data of Shanghai, China. A numerical model has been developed to study the effects of the new kind of composite wall (solar composite wall) integrated PCM. Consequently, it is aimed to avoid some futile attempts that are numerically studied to optimize the system and facilitate the process in future experiments. Thermal performance was examined using COMSOL Multiphysics, SIMPLER method software in their study (Li & Chen, 2019).

These ten studies examined the performance of the Trombe walls with configurations (such as usage PCM) by the assist of computational tools (such as TRNSYS) **in Table 2**. The Trombe wall create a more efficient system to be designed by utilizing the ability of PCM to store solar energy in a latent heat means (due to the phase change temperature to be selected of the PCM).

Table 2 *Literature Review about Trombe Wall*

Year	Author(s)	Source Title	Studied Location	Climate Type	Building Type	Material Type	Simulation Tool	Simulation Type	Study Type
2020	Chr. Lamnatou, G. Notton, D. Chemisana, C. Cristofari	Storage systems for building-integrated photovoltaic (BIPV) and building-integrated photovoltaic/thermal (BIPVT) installations: Environmental profile and other aspects	Not directly stated	No climate data	No building type is mentioned.	No material type is mentioned.	No simulation program is mentioned.	No simulation type is mentioned.	experimental & theoretical study
2019	Mehran Rabani, Mehrdad Rabani	Heating performance enhancement of a new design trombe wall using rectangular thermal fin arrays: An experimental approach	Yazd, Iran	Hot arid climate	experimental test room equipped with passive solar Trombe wall system	foam along with a mixture of thatch and concrete (thermal insulating material)	No simulation program is mentioned.	thermal performance	experimental study
2019	Wei Li, Wei Chen	Numerical analysis on the thermal performance of a novel PCM-encapsulated porous heat storage Trombe-wall system	Shanghai, China	Not directly stated	composite wall system based on PCM	PCM, glass, fluid, PCM wall	COMSOL Multiphysics, SIMPLER method	thermal performance	experimental study
2019	Na Zhu, Shanshan Li, Pingfang Hu, Fei Lei, Renjie Deng	Numerical investigations on performance of phase change material Trombe wall in building	Wuhan, China	Not directly stated	Reference Trombe wall room and PCM Trombe wall room	plaster, concrete, insulation, glass, PCM	Differential Scanning Calorimeter (DSC), TRNSYS software	thermal performance, energy performance, thermal comfort	experimental & theoretical study
2019	Shanshan Li, Na Zhu, Pingfang Hu, Fei Lei, Renjie Deng	Numerical study on thermal performance of PCM Trombe Wall	Wuhan, China	Not directly stated	PCM trombe wall room	PCM, concrete, plaster, insulation, glass	TRNSYS software	thermal performance	experimental & theoretical study
2013	Basak Kundakcı Koyunbaba, Zerrin Yılmaz, Koray Ulgen	An approach for energy modeling of a building integrated photovoltaic (BIPV) Trombe wall system	Izmir, Turkey	Mediterranean	test room	concrete, glass, masonry	Computational Fluid Dynamics (CFD), Ansys CFX, Monte Carlo Model	thermal performance	experimental & theoretical study
2013	Meriem Soussi, Moncef Balghouthi, Amenallah Guizani	Energy performance analysis of a solar-cooled building in Tunisia: Passive strategies impact and improvement techniques	Borj Cedria, Tunisia	Not directly stated	solar cooled office building (with three scenarios)	standard constructions and materials provided by ASHRAE	TRNSYS (Transient System Simulation Program)	thermal performance	experimental & theoretical study
2011	Samar Jaber, Salman Ajib	Optimum design of Trombe wall system in Mediterranean region	Amman, Jordan	Mediterranean	typical Jordanian residential building “Dar”	concrete, glass, masonry	TRNSYS software	thermal performance	No study type is mentioned.
2010	Aslıhan Kurnuç Çırakman	Faz Değiştiren Madde İçeren Bina Güney Duvarının Deneysel Olarak İncelenmesi - An Experimetal Investigation of The South Wall of The Building Integrated with Phase Change Material	Erzurum, Turkey	cold climate region	test room	GR41, GR35 insulation, brick, PCM - encapsulated plaster and novel designed Transparent Insulation Material (TIM)	No simulation program is mentioned.	No simulation is done.	experimental study
2004	Piia Lamberg, Reijo Lehtiniemi, Anna-Maria Henell	Numerical and experimental investigation of melting and freezing processes in phase change material storage	Not directly stated	No climate data	two different kinds of PCM storage wall	PCM (paraffin)	FEMLAB software operates in the MATLAB 6.1	temperature range	experimental & theoretical study

2.3. Double Skin Facade

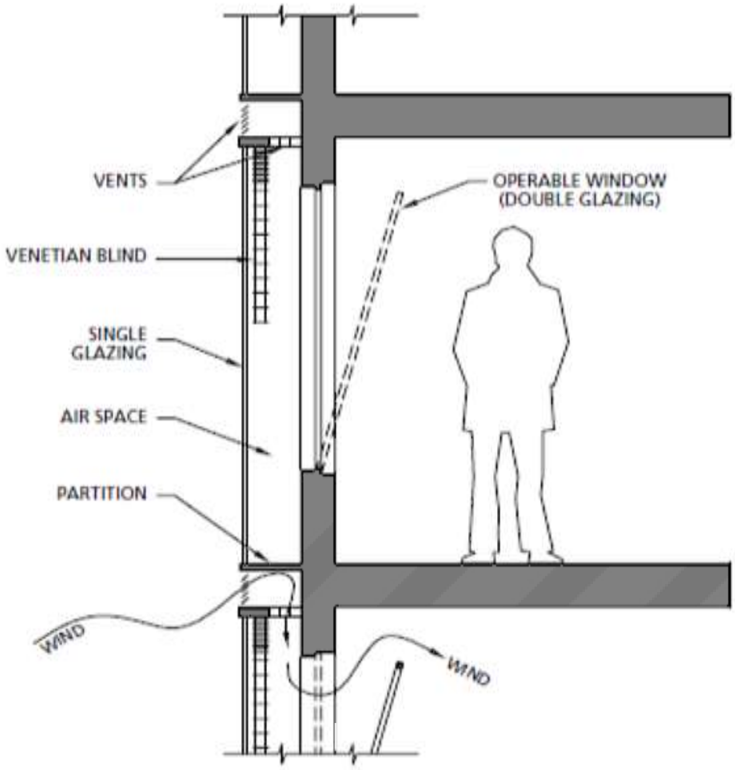


***Figure 5** Double-skin façade partial section (Lechner, 2015)*

Double skin facade (DSF) is a type of passive solar wall heating system that consists of two skins or briefly two layers of glass facades **in Fig. 5**. This section will provide seven studies examined in relation to double skin facade.

Chantawong et al. (2012) worked on a comparison of thermal performance with photovoltaic panel between glass block double-skin walls and chimney walls. This study confirms that the glazed solar chimney walls (GSCW) are extremely suitable for hot countries: by improving air circulation, it can reduce heat gain from glass walls, which can assist increase the thermal comfort of residents. Since natural ventilation does not use electrical energy, the proposed system **also** aims to conserve energy and environment. The temperature difference between the room and the environment has been achieved, unlike the traditional walls of the double-skin glass with a single-layer window (Chantawong et al., 2012). Chantawong (2019) worked on a new configuration of wall solar collector integrating photovoltaic panel and PCM aimed to ensure various objectives including heat reduction, daylighting, and ventilation and investigated experimentally under Bangkok tropical climate in Thailand. The PV solar collector wall with Phase Change Material (PVSW-PCM) made of double layer was integrated into the southern side of a small house. PVSW-PCM house compared with the GW (glass wall) house with close and open DC fans. The study relied on the measurement and experimental analysis of the measured data without mentioning any simulation tool for the thermal performance analysis (Chantawong, 2019).

The other two of the studies have been studied in China. Li et al. (2017) have studied experimental and theoretical study on PCM blind systems integrated DSF building in sweltering summer and frosty winter regions of China. In the proposed system recommended in this study, the heat transfer was simulated and in comparison, with DSF integrated with conventional aluminum blind under an overheating scenario by using ANSYS Workbench FLUENT software. This study revealed that the PCM blind system has the potential for use as an effective thermal management device in DSF systems. The influence of PCM layer on the optical (solar and visual) properties of glazing systems and aims to obtain a useful data set for numerical thermal and lighting simulations of these systems (Li et al., 2017). Furthermore, C. Liu et al. (2017) have studied on an experimental and theoretical study about the effect of PCM thickness on thermal performance of a PCM-filled double glazing facades in the small-scale test facility at Northeast Petroleum University in Daqing, China where in the cold area of Northeast China. The results demonstrate that PCM thickness increases, the tendency of interior temperature and total transmitted energy variation is not consistent and has shown that in some variations it can reverse the total transmitted energy for some PCMs. PCM which is 12-30 mm thickness and has melting temperature is 14-16 ºC that has recommended in Northeastern China (C. Liu et al., 2017).

Elarga et al. (2016) worked on a theoretical study by a PCM transient model. Glazed office type of building was analyzed in this study for Venice (Italy), Helsinki (Finland) and Abu Dhabi (United Arab of Emirates) to represent warm, cold-humid and hot-arid climates respectively. The main scope of the study is to obtain a simpler model by performing numerical simulations to evaluate the integration of the PCM layer into fully glazed facade buildings. The thermal and electrical impact of the study was investigated. The study evaluated the performances of material types (i.e. glass, paraffin waxes "(Rubitherm) RT42 and RT55") via Window (DOE, v 6.3.9.0, 2010) within TRNSYS and MATLAB Simulink tools. The tools calculated the heat gains and solar gains of DSF with PV-PCM integration (Elarga et al., 2016).

Gracia et al. (2015)’s experimental study was on ventilated facade with PCM which is located in the south wall with a metallic and a wooden structure. The potential benefits of an innovative ventilated double skin facade (VDSF) with PCM, which were evaluated experimentally only for Mediterranean-continental climate, are moreover extended for different climates in the world. Therefore, Energy Plus weather data has used. The aim of this study is to determine the potential and suitability of this system operation for cooling purposes around the world under different climates (Gracia et al., 2015).

Some of the studies have not specified climate data and studied location which is one of the key factors to change the performance of the design. Goia et al. (2015) worked on experimental study about PCMs glazing systems mainly on commercial building. No simulation program was mentioned however thermal analysis related to the PCM materiality (i.e. advanced transparent materials, extra-clear glass pane, paraffin). Both liquid and solid state of the PCM (a paraffin wax) was investigated. In addition, opportunities (e.g. good daylight gain and low glare risk, reduction and time-shift of solar gain) and drawbacks (e.g. increased weight, volume change and translucent aspect) of integration of PCM glazing systems in buildings are illustrated. New configurations of PCM glazing systems can be simulated using the data set of optical properties presented in this paper and optimization of such a component can be carried out for different boundary conditions, such as climate or building types (Goia et al., 2015).

Weinläder et al. (2005) worked experimental study on south facade panel with three kinds (RT25, S27[$CaCl_2 \cdot 6H_2O$] and L30[$LiNO_3 \cdot 3H_2O$]) of PCM in Würzburg, Germany. PCM panels are installed in a new type of ventilated facade to reduce the consumption for heating and cooling. The tools calculated the heat losses, heat gains and solar gains of a south oriented double glazing (DG) facade with and without various kinds of PCM. DG without PCM compared to a facade panel with PCM demonstrates nearly 30% less heat losses on south facades. Solar heat gains are also reduced by about 50%. The facade panels with PCM improve thermal comfort in winter, especially during evenings. In summer, it demonstrates low heat gains by reducing peak cooling loads during the day. Additional heat gains in the evening can be drawn off by night-time ventilation. When using a PCM with a low melting temperature of up to 30 ℃, thermal comfort during the summer months was also increased during the day compared to double glazing without or with inner sun protection (Weinläder et al., 2005).

These seven studies examined in the variety of climate, material, PCM thickness, and simulation methods reviewed highlight application of the double skin facade to reduce energy consumption **in Table 3.** The integration of PV-PCM and DSF-PCM systems aimed to achieve various objectives such as heat reduction, daylight and ventilation. PCM and integrated DSF systems have proven to be available in hot and cold zones such as China.

Table 3 *Literature Review about Double Skin Façade*

Year	Author(s)	Source Title	Studied Location	Climate Type	Building Type	Material Type	Simulation Tool	Simulation Type	Study Type
2019	Preeda Chantawong	Experimental Investigation of Thermal Performance of a Multipurpose PV Solar Collector Wall with Phase Change Material	Thailand	tropical zone	small house	autoclaved aerated concrete blocks with cement plastering.	No simulation program is mentioned.	thermal performance	experimental study
2017	Yilin Li, Jo Darkwa, Georgios Kokogiannakis	Heat transfer analysis of an integrated double skin façade and phase change material blind system	China	hot summer and cold winter regions	blind systems integrated DSF building	glass, PCM (PX35 of RUBITHERM company), aluminum	ANSYS FLUENT 14.0	CFD analysis, temperature, velocity	experimental & theoretical study
2017	Changyu Liu, Yangyang Wu, Dong Li, Yingming Zhou, Zhiguo Wang, Xiaoyan Liu	Effect of PCM thickness and melting temperature on thermal performance of double-glazing units	Northeast Petroleum University in Daqing, China	different climatic condition in the cold area of Northeast China	PCM-filled double glazing facades with different thickness of PCM	glass, different PCM thicknesses(seven kinds of pcm thickness)	Jinzhou Sunshine/TBQ-4-5 solar spectral radiometer	thermal performance, solar radiation and temperature	experimental & theoretical study
2016	Hagar Elarga, Francesco Goia, Angelo Zarrella, Andrea Dal Monte, Ernesto Benini	Thermal and electrical performance of an integrated PV-PCM system in double skin façades: A numerical study	Venice (Italy), Helsinki (Finland) and Abu Dhabi (United Arab of Emirates)	warm temperate, snow fully humid and hot arid	PCM transient model	glass, RT42-Organic pcm, RT55-Organic pcm, paraffin waxes (Rubitherm)	Window (DOE, 2010), TRNSYS, MATLAB, Simulink	thermal analysis, solar radiation	theoretical study
2015	Alvaro de Gracia, Lidia Navarro, Albert Castell, Luisa F. Cabeza	Energy performance of a ventilated double skin facade with PCM under different climates	Quito, Berlin, San Francisco, Mexico DF, Johannesburg, Montreal, Stockholm, Moscow, Brasilia, Antofagasta, Auckland	equatorial, arid, warm temperate (main climate), snow	ventilated facade with PCM is located in the south wall with a metallic and wooden structure	PCM (SP-22) [PCM without hysteresis, such as RT21]	EnergyPlus	energy performance, thermal performance	experimental study
2015	Francesco Goia, Michele Zinzi, Emiliano Carnielo, Valentina Serra	Spectral and angular solar properties of a PCM-filled double glazing unit	Not directly stated	No climate data	PCMs glazing systems in building	advanced transparent materials, extra-clear glass pane, paraffin	No simulation program is mentioned.	thermal analysis	experimental study
2005	Helmut Weinläder, Andreas Beck, Jochen Fricke	PCM-facade-panel for daylighting and room heating	Würzburg, Germany	climate data for Würzburg, Germany.	facade panel with all of the three kinds of PCM in a south facade	RT25, S27 and L30	No simulation program is mentioned.	thermal performance, thermal comfort	experimental study

2.4. Attached Greenhouse System

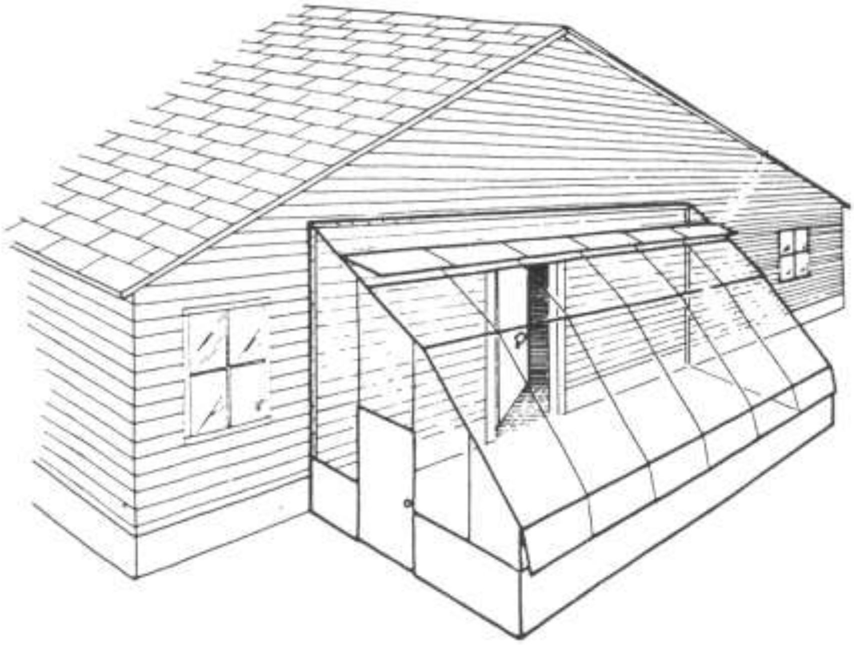


Figure 6 *Attached greenhouse system (Retrieved from https://extension.okstate.edu/fact-sheets/the-hobby-greenhouse-2.html, Copyright 2020)*

Attached greenhouse system is a type of transparent structure that is attached to the building as seen **in Fig. 6**. In this section, five studies are examined as attached greenhouse system. The climate type is not specified for one of them however there meteorological data is used. It has been studied with theoretical and experimental methods. No study type is mentioned for one of them.

Sanjuan-Delmás et al. (2018) worked on vertical agricultural buildings. In this study, an integrated roof-top greenhouse (i-RTG) in a building offers a comprehensive environmental assessment of food production. The aim of the study is to show the feasibility of the system and to calculate the environmental impacts of the entire life cycle, the infrastructure to the end of life, by comparing these effects with these convention productions. At the end of this study, the optimization of the amount of infrastructure material and the management of the operation have been concluded that the administration could lead to better environmental performance in future i-RTG projects (Sanjuan-Delmás et al., 2018).

He et al. (2018) worked on the effect of the back-wall vent dimension on solar greenhouse cooling was investigated by CFD. The results demonstrated that the average air temperature in solar greenhouse with removable back walls was reduced by approximately 1.7 ℃ and the highest temperature dropped by approximately 5.8 ℃ compared with the traditional solar greenhouse with a brick back-wall. The results suggest that a back-wall vent of 1.4 m increased inside the ventilation efficiency in a solar greenhouse with removable back-walls (He et al., 2018). Taki et al. (2018) worked on a comprehensive examination was presented with the simulation of heat and mass transfer by focusing on the basic strategies of energy saving technologies. The share of current greenhouse systems in total energy consumption was examined in detail. In the scope of this research, sustainable based solutions such as photovoltaic (PV) modules, solar thermal (T) collectors, hybrid PV/T collectors and systems, PCM and underground-based heat storage techniques, energy-saving heat pumps, alternative facade materials have been researched for better thermal insulation and power generation. With the findings obtained from the study, up to 70% of energy savings can be achieved through the appropriate strengthening of traditional greenhouses. This modelling aimed solar greenhouses designed for all agricultural areas to obtain maximum solar radiation and reduce the request for fossil fuels (Taki et al., 2018).

Graamans et al. (2018) worked on a research assesses the potential on closed plant production systems in harsh climates with either low or high temperatures and solar radiation levels. This study was also conducted for three different climate regions, examining an internal climate impact on resource efficiency in plant factories and greenhouses (Graamans et al., 2018). Çakır and Şahin (2015) worked on compares between five common greenhouse types with regard to total solar radiation gaining rates on the MATLAB platform using season under some assumptions. This model has been applicable and suitable for other buildings and places on the world. The width of greenhouse length ratio and greenhouse azimuth angle (GAA) are designated. Furthermore, the possibility of using greenhouses in cold climate regions has been researched and found to be appropriate. The shape and type of the roof are effective parameters on solar energy gaining rates of greenhouses (Çakır & Şahin 2015).

These five studies examined climates, types of materials, and simulation methods reviewed highlight application of the greenhouse system to specified performance **in Table 4.** The studied climate facilitated the collection of information for the variety of material covers and simulation methods used.

Table 4 *Literature Review about Greenhouse*

Year	Author(s)	Paper Name	Location	Climate Type	Building Type	Material Type	Simulation Tool	Simulation Type	Study Type
2018	Xiangli He, Jian Wang, Shirong Guo, Jian Zhang, Bin Wei, Jin Sun, Sheng Shu	Ventilation optimization of solar greenhouse with removable back walls based on CFD	Suqian (Jiangsu, China)	Not directly stated	two experimental solar greenhouses; removable back wall greenhouse (RG) and traditional solar greenhouse (TG)	PVC film, Air, Soil, Brick, Polystyrene board	ANSYS FLUENT	CFD analysis, indoor and outdoor temperature, solar radiation and air flow distributions	experimental & theoretical study
2018	David Sanjuan-Delmás, Pere Llorach-Massana, Ana Nadal, Mireia Ercilla-Montserrat, Pere Muñoz, Juan Ignacio Montero, Alejandro Josa, Xavier Gabarrell, Joan Rieradevall	Environmental assessment of an integrated rooftop greenhouse for food production in cities	Spain	Mediterranean	integrated rooftop greenhouse (i-RTG)	greenhouse structure (the steel framework and the polycarbonate sheets), steel, glass fibre-reinforced polyester	Simapro 8.2 software (ReCiPe method, from the Ecoinvent 3 database)	Not directly stated	experimental & theoretical study
2018	Morteza Taki, Abbas Rohani, Mostafa Rahmati-Joneidabad	Solar thermal simulation and applications in greenhouse	Not directly stated	different climate conditions	No building type is mentioned.	alternative facade materials, cover materials (Polyethylene, Glass, Filon and Polycarbonate)	many types of software	Not directly stated	experimental study
2018	Luuk Graamans, Esteban Baeza, Andy van den Dobbelsteen, Ilias Tsafaras, Cecilia Stanghellini	Plant factories versus greenhouses: Comparison of resource use efficiency	Kiruna (Sweden), Amsterdam (Netherlands) and Abu Dhabi (United Arab Emirates)	Not directly stated	highly insulated opaque box plant factories and Venlo type greenhouses	facade construction: plant factory (gypsum – PUR – gypsum), greenhouse (standard single glass cover)	KASPRO, DesignBuilder, EnergyPlus, MATLAB	performance analysis solar radiation and temperature	No study type is mentioned.
2015	Uğur Çakır, Erol Şahin	Using solar greenhouses in cold climates and evaluating optimum type according to sizing, position and location: A case study	Bayburt, Turkey	cold climatic region	Even-span, uneven-span, vinery, semi-circular and elliptic types of greenhouses	greenhouse transparent covering material	MATLAB	solar radiation	theoretical study

2.5. Phase Change Material (PCM)

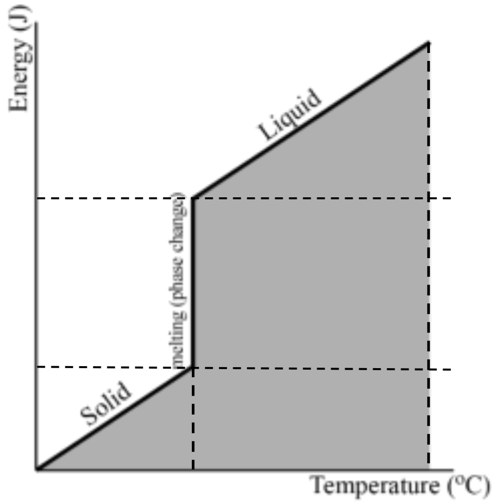


Figure 7 *Phase Change Diagram*

Phase Change Material (PCM) is a type of the materials that st^{o}re and release energy by means of phase adapting **in Fig. 7.** Chapter 4 is mentioned in detail. This section will provide eighteen studies examined in relation to PCM. These are mostly examining the theoretical and experimental studies. Different climate types have been applied. Ten of these studies do not specified any location however for one of them climate data has been specified.

Souayfane et al. (2016) worked on experimental and theoretical study in different climates and conditions. Many experimental and simulation studies have been presented showing the effect of PCM on the building’s thermal performance and the effect of PCM have been discussed for PCM applications for cooling purposes and factors in this article (Souayfane et al., 2016). Cascone and Perino (2015) worked on a deficiency of information about thermal-physical properties of PCM. A method to predict the specific heat temperature curve through the reverse modeling of PCM brings experimental data together with a numerical tool that can simulate the addition of PCMs of multiple layered walls. Reverse method modeling used to predict a PCM's specific temperature curve has been presented and multi-layered walls have been created by combining experimental data with a numerical tool to incorporate PCMs. The results were verified in tests on different samples and compared to low-speed DSC measurement (Cascone & Perino, 2015). Kenisarin (2014) worked on results of previous research on the characteristics, compositions and compounds of many organic substances such as pass temperatures, fusion, heat capacity and thermal conductivity (Kenisarin, 2014). Cabeza et al. (2011) worked on different solutions have been introduced to the technical problems found when the latest publications related to the use of PCMs are examined in buildings (Cabeza et al., 2011). Dutil et al. (2010) worked on an exhaustive review of numerical methods applied to the solutions of heat-transfer problems involving PCMs for thermal energy storage (Dutil et al., 2010). Sharma et al. (2009) worked on the investigation and analysis of the available thermal energy storage technology with PCMs with different applications (Sharma et al., 2009). Tyagi and Buddhi (2007) worked on the state of art of various possible PCM-based technologies for heating and cooling of buildings. Materials used by means of researchers as potential PCMs (lying in the range of 20-32 ℃) for human comfort in buildings are described. The systems discussed in this paper have good potential for reducing the heating and cooling load in building through PCM (Tyagi & Buddhi, 2007). Auzeby et al. (2017) worked on evaluated studies on whether PCMs are available in the UK to solve overheating problems in residential buildings (Auzeby et al., 2017). This study provides useful evidence about the use of PCMs in UK residential applications. Zalba et al. (2003) worked on a review has been carried out of the history of thermal energy storage with solid–liquid phase change. Three aspects have been the focus of this review: materials, heat transfer and applications (Zalba et al., 2003). The paper contains listed over 150 materials used in research as PCMs, and about 45 commercially available PCMs. The paper lists over 230 references. Akeiber et al. (2016) worked on recent studies of the application of PCMs for passive cooling in buildings. Comprehensive list of different organic, inorganic and eutectic PCMs appropriate for passive cooling in buildings are reviewed in the literature (Akeiber et al., 2016). Fateh et al. (2017) worked on developing a detailed dynamic model. This study aims to examine the effects of these dynamic model and PCMs on the insulation layers of light walls (Fateh et al., 2017). Saffari et al. (2017) worked on PCM enhanced buildings. With this study, it is aimed to examine the passive cooling potential of these buildings with energy simulation tools (Saffari et al., 2017). Chou et al. (2013) worked on an experimental and theoretical study on thermal performance of the PCM in the indoor space. An innovative design for metal–sheet roofing was introduced using the phase change effect of PCM (Chou et al., 2013). Čurpek and Hraska (2016) worked on a dynamic thermal office building model with integrated ventilated PV facade/solar air collector system in climatic conditions of Bratislava, Slovakia (Čurpek & Hraska, 2016). Behzadi and Farid (2011) worked on the effect of the use of PCM on indoor air temperature. It shows that it can effectively reduce daily fluctuations and maintain the desired comfort level for a longer period of time (Behzadi & Farid, 2011). Bruno (2004) worked on the research studies and the systems used. Potential future instructions about PCMs for space heating and cooling in buildings were studied. The review of numerical studies shows that for buildings without mechanical cooling, indoor air temperature and energy consumption is significantly reduced (Bruno, 2004). Ozdenefe and Dewsbury (2012) worked on an experimental study of PCM’s temperature reduction capacity in a single room under the weather conditions of Cyprus to improve their energy performance (Ozdenefe & Dewsbury, 2012).

Two of studies have been studied in China. Li et al. (2017) have studied thermal performance of integrated lightweight buildings with PCMs (PCM blind systems integrated DSF building) in hot summer and cold winter regions of China (Li et al., 2017). Sharma et al. (2004) worked on about the previous works on PCMs and latent heat storage systems. Recent innovations on PCM applications are included for the awareness about new applications (Sharma et al., 2004).

These eighteen studies have examined different type of climate, different type of materials, and simulation methods reviewed highlight application of the phase change materials to specified thermal performance **in Table 5**. These studies will assist to find the suitable PCM and different techniques for various applications.

Table 5 *Literature Review about PCM*

Year	Author(s)	Paper Name	Location	Climate Type	Building Type	Material Type	Simulation Tool	Simulation Type	Study Type
2017	Yanru Li, Yan Wang, Xi Meng, Wei Zhang and Enshen Long	Research on thermal performance improvement of lightweight buildings by integrating with phase change material under different climate conditions	China	in five different climatic conditions	a lightweight building integrated with PCMs	PCM, Metal sheet, Polystyrene foam board, Plasterboard	EnergyPlus	thermal performance	experimental & theoretical study
2017	Mohammad Saffari, Alvaro de Gracia, Svetlana Ushak, Luisa F. Cabeza	Passive cooling of buildings with phase change materials using whole-building energy simulation tools: A review	Not directly stated	No climate data	many types of buildings	PCM	EnergyPlus TRNSYS ESP-r	thermal performance	No study type is mentioned.
2017	Amirreza Fateh, Felix Klinker, Michael Brütting, Helmut Weinläder, Francesco Devia	Numerical and experimental investigation of an insulation layer with phase change materials (PCMs)	Not directly stated	No climate data	various locations inside a light wall of building envelope	XPS, Energain® PCM, BASOTECT, wall layer materials	MATLAB Simulink	thermal performance	experimental & theoretical study
2017	Marine Auzeby, Shen Wei, Chris Underwood, Chao Chen, Haoshu Ling, Song Pan, Bobo Ng, Jess Tindall, Richard Buswell	Using phase change materials to reduce overheating issues in UK residential buildings	Aberdeen, Leeds and Southampton in UK	maritime climate (also influenced by continental weather systems)	residential buildings	BJUT (Beijing University of Technology) PCM	DesignBuilder EnergyPlus	thermal performance	experimental study
2016	Farah Souayfane, Farouk Fardoun, Pascal-Henry Biwole	Phase change materials (PCM) for cooling applications in buildings: A review	Not directly stated	different climates and conditions	No building type is mentioned.	PCM (consist of BioPCM...)	Not directly stated	thermal performance	experimental & theoretical study
2016	Hussein Akeiber, Payam Nejat, Muhd Zaimi Abd. Majid, Mazlan A.Wahid, Fatemeh Jomehzadeh, Iman Zeynali Famileh, John Kaiser Calautit, Ben Richard Hughes, Sheikh Ahmad Zaki	A review on phase change material (PCM) for sustainable passive cooling in building envelopes	different cities	different climates and conditions	many types of buildings	PCM types	COMSOL Multiphysics, ANSYS Fluent, EnergyPlus, TRNSYS	CFD analysis, thermal performance, energy performance, thermal comfort, solar radiation	experimental & theoretical study
2016	Jakub Čurpek, Jozef Hraska	Simulation Study on Thermal Performance of a Ventilated PV Façade Coupled with PCM	Bratislava, Slovakia	Bratislava Airport, Slovakia of based ASHRAE design weather data	simple story office building	Solar PV panel (photovoltaic glass), aluminum container of PCM, BioPCM (M27/Q21)	DesignBuilder, EnergyPlus, Conduction Finite Difference (ConFD) solution algorithm	thermal performance	No study type is mentioned.
2015	Ylenia Cascone, Marco Perino	Estimation of the thermal properties of PCMs through inverse modelling	Not directly stated	No climate data	three samples of multilayer walls with PCM materials	PCM, XPS, mineral wool and gypsum plasterboard	Differential Scanning Calorimetry (DSC) T-history method	Not directly stated	experimental & theoretical study
2014	Murat M. Kenisarin	Thermophysical properties of some organic phase change materials for latent heat storage: A review	Not directly stated	No climate data	No building type is mentioned.	PCM types	No simulation program is mentioned.	Not directly stated	No study type is mentioned.
2013	Huann-Ming Chou, Chang-Ren Chen, Vu-Lan Nguyen	A new design of metal-sheet cool roof using PCM	Kun Shan University, Tainan, Taiwan	different climate conditions	PCM roof model	PCM, metal-sheet roof materials and colour	COMSOL Multiphysics	solar radiation and thermal performance	experimental & theoretical study

2012	Murat Ozdenefe, Jonathan Dewsbury	Dynamic Thermal Simulation of A PCM Lined Building with Energy Plus	Larnaca, South Cyprus	Not directly stated	PCM lined building	PCM lining	EnergyPlus	thermal performance	experimental study
2011	L.F. Cabeza, A. Castell, C. Barreneche, A. de Gracia, A.I. Fernández	Materials used as PCM in thermal energy storage in buildings: A review	Not directly stated	No climate data	No building type is mentioned.	usage and kind of PCM	No simulation program is mentioned.	Not directly stated	No study type is mentioned.
2011	Sam Behzadi, Mohammed M. Farid	Experimental and numerical investigations on the effect of using phase change materials for energy conservation in residential buildings	Auckland, New Zealand	New Zealand weather conditions	office sized test rooms	PCM (paraffin)	SUNREL software	thermal performance	No study type is mentioned.
2010	Yvan Dutil, Daniel R. Rousse, Nizar Ben Salah, Stephane Lassue, Laurent Zalewski	A review on phase-change materials: Mathematical modeling and simulations	Not directly stated	No climate data	No building type is mentioned.	Rock, Water, Organic PCM, Inorganic PCM	No simulation program is mentioned.	Not directly stated	experimental & theoretical study
2009	Atul Sharma, V.V. Tyagi, C.R. Chen, D. Buddhi	Review on thermal energy storage with phase change materials and applications	Not directly stated	No climate data	No building type is mentioned.	various container materials, PCM examples	No simulation program is mentioned.	Not directly stated	No study type is mentioned.
2007	Vineet Veer Tyagi, D. Buddhi	PCM thermal storage in buildings: A state of art	Not directly stated	No climate data	No building type is mentioned.	usage of PCM	No simulation program is mentioned.	Not directly stated	No study type is mentioned.
2005	Dr Frank Bruno	Using Phase Change Materials (PCMs) For Space Heating and Cooling in Buildings	University of South Australia in Adelaide	Not directly stated	a typical house	PCMs in gypsum board, PCMs in plaster or other wall covering materials	CHEETAH, developed at the CSIRO [30].	No simulation type is mentioned.	experimental study
2004	Someshower Dutt Sharma, Hiroaki Kitano, Kazunobu Sagara	Phase Change Materials for Low Temperature Solar Thermal Applications	Not directly stated	No climate data	No building type is mentioned.	No material type is mentioned.	No simulation program is mentioned.	Not directly stated	experimental & theoretical study
2003	Belen Zalba, Jose M. Marin, Luisa F. Cabeza, Harald Mehling	Review on thermal energy storage with phase change: materials, heat transfer analysis and applications	Not directly stated	No climate data	No building type is mentioned.	No material type is mentioned.	No simulation program is mentioned.	Not directly stated	theoretical study

2.6. Attached Greenhouse System with PCM

In this section, PCM with the attached greenhouse system has been examined with seven studies. The climate type is not specified for three of them. It has been studied with theoretical and experimental methods. No study type is mentioned for one of them.

Chen et al. (2018) worked on the solar greenhouse that use of PCM on the northern wall. It presents the results of a study in which important parameters made in Urumchi, China, were compared in two parts of a solar greenhouse (with a ventilated north wall and a traditional north wall). An active-passive ventilation wall with phase change material has been proposed. A comparative study was designed to justify its advantages over traditional walls (Chen et al., 2018). Berroug et al. (2011) worked on the thermal performance of a north wall made with PCM as a storage medium in east–west oriented greenhouse is analyzed and discussed (Berroug et al., 2011).

Llorach-Massana et al. (2016) mentioned that this paper reports a study of different design solutions for a root zone heating system, based on thermal energy storage with PCM. Root zone heating systems increase product quality and efficiency. However, these systems are based on the use of non-renewable fuels. This article reports a study on different design solutions for a root zone heating system based on thermal energy storage with PCM. The results show that the best melting temperature for application under study is 15 ℃. To increase the efficiency of the system, PCMs can be macro encapsulated and wrap the entire perlite bag. An appropriate melting and freezing temperature for a root zone passive heating system with PCM in Mediterranean greenhouses seems to be 15 ℃. A melting/freezing temperature of 12 ℃ does not ensure the freezing of the PCM if temperatures do not fall under 10 ℃ (Llorach-Massana et al., 2016).

Mangold and Selberg (2015) explored the addition of the greenhouse building as an alternative renovation strategy for Brogården buildings in Alingsås. The project has been extensively documented, so it has been found to be an object suitable for study. The greenhouse proposal was analyzed in relation to reference cases in three areas: sustainability-ecology, economy and society. To achieve this, all cases were modeled in COMSOL Multiphysics, which affects physics events and analyzes the use of PCM.

It has been found that the greenhouse proposal is not an adequate replacement in the scenario under investigation, but it can be a reasonable investment for a building with higher initial performance or as part of a renovation package. The greenhouse has a pronounced effect in reducing the energy flows of the outer wall, but it has less impact since it is assumed that PCMs are added as heat storage (Mangold and Selberg, 2015).

Najjar and Hasan (2008) worked on a mathematical model for temperature of phase change material is developed, solution of this model represents fairly well the experimental results. The PCM is incorporated in a greenhouse model the combined greenhouse model and PCM models are solved in order to determine the inside greenhouse air temperature (Najjar and Hasan, 2008).

Liu et al. (2006) focused on the greenhouse that needs additional heat at night to provide an indoor air temperature above 20 ℃ and applies a new shape stabilized PCM composite wallboard to the inner surface of the north wall of the greenhouse. Based on the phase change heat transfer theory, by establishing the phase change greenhouse model, the effect of solar radiation and ambient temperature on the heat transfer process in the greenhouse was investigated.
The aim of the study was to determine whether PCMs were melting or not during cold periods in a Mediterranean greenhouse. The energy saving properties of greenhouses, which adopted PCM wall coverings in the winter season, were investigated. It can be seen that PCM can be used appropriately to increase the efficiency of the system by utilizing solar energy and to decrease the heat load in the winter. Research results show that when the phase change temperature of PCM is 26 ℃, the enthalpy is 60 kJ/kg and the mixing rate is 40%, the energy saving rate of the greenhouse can reach 20% during the winter (Liu et al., 2006).

Kürklü (1998) stated that energy storage efforts to heat greenhouses date back to the 1980s and that Japan is the country that focuses on these studies with PCMs. He stated that the amount of PCM and melting temperatures per square meter greenhouse area varies from application to application. He mentioned the previous studies and the PCMs used and their features. However, all studies imply that PCMs can be used for both energy storage and humidity control in greenhouses for energy management, given the correct selection and design of the entire system (Kürklü, 1998).

These seven studies examined in the variety of climate, material, PCM thickness and simulation methods reviewed to reduce energy consumption **in Table 6.**

As a result;

- These studies examined the variety of climate, types of materials, different PCM thicknesses and simulation methods reviewed to reduce energy consumption.
- It is argued that sustainable technologies can be designed together to create a more efficient system.

In previous sections, the research on different use of glass structures has been conducted as a method of coping with climate change and high energy consumption, and at this point, thermal energy storage properties have reached studies on phase change material. PCM, one of the thermal energy storage systems, is the main focus that needs to be addressed in terms of its energy consumption reduction feature.

Table 6 *Literature Review about Greenhouse with PCM*

Year	Author(s)	Paper Name	Location	Climate Type	Building Type	Material Type	Simulation Tool	Simulation Type	Study Type
2018	Chao Chen, Haoshu Ling, Zhiqiang (John) Zhai, Yin Li, Fengguang Yang, Fengtao Han, Shen Wei	Thermal performance of an active-passive ventilation wall with phase change material in solar greenhouses	Urumchi, China	Not directly stated	solar greenhouse	PCM wallboards, Hollow blocks, Solid blocks, Polystyrene boards, Film, Felt, Air, Soil	MATLAB	thermal performance, solar radiation and outdoor air temperature	experimental & theoretical study
2016	Pere Llorach-Massana, Javier Peña, Joan Rieradevall, Juan Ignacio Montero	Analysis of the technical, environmental and economic potential of phase change materials (PCM) for root zone heating in Mediterranean greenhouses	Cabrils (Barcelona, Spain)	Mediterranean climate	greenhouse covered with a single PE layer opaque	covered with a single PE layer opaque to far infrared radiation. - PCM RT12 [29], RT15 [30] and RT18HC [31]	Ecoinvent 2 database, Simapro7	thermal efficiency, environmental performance	experimental study
2015	Oskar Mangold, Peter Selberg	Renovating with a greenhouse and Phase Change Material	Sweden	Not directly stated	greenhouse case with PCM in a single building	RT10 (PCM Rubitherm) and alternatives of PCM	Pareto assembly, COMSOL Multiphysics®, Meteonorm (for radiation) Landvetter (for temperature)	CFD analysis, energy simulations, solar radiation	No study type is mentioned.
2011	F. Berroug, E.K. Lakhal, M. El Omari, M. Faraji, H. El Qarnia	Thermal performance of a greenhouse with a phase change material north wall	Marrakech, Morocco	Mediterranean climate	north wall of the greenhouse	north wall PCM, plants, inside air and plastic cover	Not directly stated	thermal performance	experimental & theoretical study
2008	Atyah Najjar, Afif Hasan	Modeling of greenhouse with PCM energy storage	Palestine, Al-Aroub	Not directly stated	greenhouse model with PCM energy storage	PCMs, cover with Single Polyethylene	No simulation program is mentioned.	No simulation type is mentioned.	experimental study
2006	Yuning Liu, Chao Chen, Haifeng Guo, Hailin Yue	An Application of Phase Change Technology in a Greenhouse	DaXing (Beijing, China)	cold climate	greenhouse model (traditional greenhouse)	concrete grout, brick, Film (heat insulating layer, PVC(film)), PCM wallboard	MATLAB	solar radiation and environment temperature	experimental study
1998	Ahmet Kürklü	Energy storage applications in greenhouses by means of phase change materials (PCMs) : a review	Not directly stated	cold climates	greenhouse with phase change energy storage system	Paraffins, $CaCl_2 \cdot 6H_2O$, $Na_2SO_4 \cdot 10H_2O$, Polyethylene Glycol-PEG, glass and plastic covered	Not directly stated	Not directly stated	experimental study

CHAPTER 3

PASSIVE SOLAR HEATING SYSTEMS

In this section, studies have been made about the several types of passive solar energy gains in buildings. Passive solar systems, external walls, roofs and floors cause the use of building components to gain control over solar heat generation to reduce mechanical HVAC usage in the building along with the reduction of electricity generation, energy consumption in some cases. The systems that are presented in this review are passive solar heating systems (followed as direct gain systems, indirect gain systems and isolated gain systems). Passive solar system, which collects, stores and redistributes solar energy without use of complex controllers such as fans and pumps, operates on an integrated approach to building design where basic building elements such as windows, walls and floors have many distinct functions. According to Lechner (2015) principally, passive solar heating includes of south-facing glazing and thermal mass (Lechner, 2015). The most common way to increase use of solar energy in buildings is to increase transparent surface areas where the south facade can comfortably take sunshine. Glass is used in collection of solar energy because it allows direct passing of important part of solar radiation. For example, sunlight in solar house passes through glass, roof and walls and is absorbed by the inside objects. Later, these objects are converted into heat energy through radiation and heated air within the building. The resulting heat energy is deposited in thermal mass by materials that depending on concrete, brick, stone, water or temperature. Temperature losses in the night and cold seasons are reduced by insulation materials while directed by sunlight, shutters, or shades. Warm or wintry weather is transmitted to the system with the assist of the vent (Kundakcı, 2004; Zeiher, 2000).

For instance, the walls not only hold the roof and keep the air out, but also act as heat storage and heat spreading elements. In this way, the various components of a building meet the architectural, structural and energy requirements simultaneously. Each passive solar heating system has at least two elements: a window (glass structure) in the south and an energy storage element consisting of thermal mass (such as rock or water) for the building. Depending on the relationship between these two elements, there are several types of passive solar systems. The better the architect designs for heat retention, the less heating will be required. It is stated that a passive solar building can provide about 80% of the required heat across of the United States (Lechner, 2015). It is important to realize that the passive solar system does more than heating the building. Most importantly, it provides passive security (resilience) because the temperature inside a passive solar building will be much higher than in a standard building (Lechner, 2015). The passive system reduces energy costs by covering some or all of the building's heating, cooling and lighting requests from solar energy (Zeiher, 2000). The passive solar heating systems are described in this section. The following sections will express the solar gain systems in three parts: direct, indirect and isolated.

3.1. Direct Gain Systems

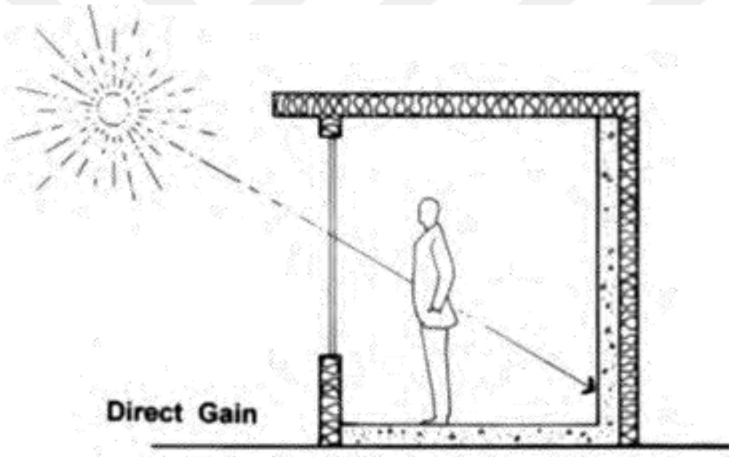


Figure 8 *Section of a direct gain (Lechner, 2015)*

In a direct gain design, solar radiation and daylight enters the house through south-facing windows and strikes masonry floors and/or walls, which absorb and store the solar heat (Retrieved from https://www.energy.gov/energysaver/energy-efficient-home-design/passive-solar-home-design Copyright (2019)). East, west and especially north-facing windows lose more heat than they have gained in the winter, while south-facing windows create a direct gain system for north hemisphere locations **in Fig. 8**. While a room cools during the night, thermal mass releases heat into the house. Some builders and homeowners consume water-filled containers located inside the living space to absorb and store solar heat. Although water stores twice as much heat as masonry materials per cubic foot of volume, water thermal storage requires carefully designed structural support. An advantage of water thermal storage is that it can be installed in an existing home in the event that the structure can support the weight (Retrieved from https://www.energy.gov/energysaver/energy-efficient-home-design/passive-solar-home-design Copyright (2019)). In the direct gain system, the more mass takes better than solar radiation as direct or reflected. The mass should have a large surface area instead of the depth. The maximum solar radiation is provided to the space through the southern windows, which is absorbed by radiation, flooring and walls. The living area is close to both massive surfaces and glass surfaces and as a result, temperature changes are felt on all surfaces of the night and day. In the event that there is not enough heat storage, there is a high temperature difference between day and night as overheating (Kundakcı, 2004). Therefore, to design the south-facing facade glazing in appropriate ratio is significant to avoid the extra heating and less loss. Thermal mass inside the building absorbs daylight to prevent overheating as well as to store this heat at night. The thermal mass inside the building then absorbs this heat, both to prevent daytime overheating and to store it for nighttime consume *(Lechner, 2015)*.

3.2. Indirect Gain Systems

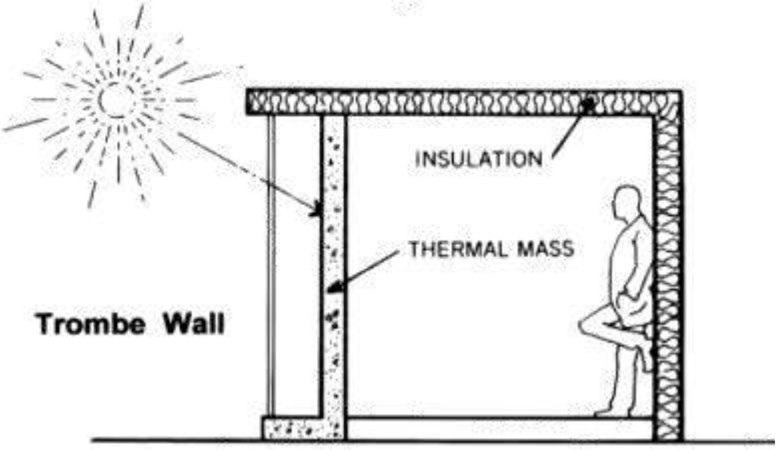


***Figure 9** Section of an indirect gain (Trombe wall) system (Lechner, 2015)*

In this passive system, heat is stored by the thermal mass between direct solar gain and living space consists of a wall just inside the south-facing glazing **in Fig. 9**. The heat is absorbed by the thermal mass during the day, since thermal mass in indirect gaining systems, is placed between glass and living space, prevents excessive temperature fluctuations during the night and day in the space separating the night life area from the direct impact of cool glass (Kundakcı, 2004). As mentioned before, the greenhouse effect traps the solar radiation in between glazing and the massive brick wall. Because the surface of the wall facing the sun is either covered with a selective coating or painted a dark color, that leads the gap receives quite hot during the day, causing heat to flow into the wall. The most generic form of this system is **Trombe Wall.** As Bainbridge (1981) mentioned that the Trombe wall was named after Professor Felix Trombe developed at France in 1966 (Bainbridge, 1981). Trombe walls supply heat without light. Since the Trombe wall is quite thick (about 30 cm) and the time lag is quite long, the heat does not reach the interior surface until evening. The thickness of this mass ensures that the temperature changes in the field of life are less and transmission of heat within the wall is delayed. If there is enough mass, the wall is able to act as a radiant heater all night long (Lechner, 2015). The wall consists of a masonry wall on the south side of a house. The heat migrates through the wall and radiates into the living space. Heat travels through a masonry wall at an average rate of one inch per hour, so the heat absorbed on the outside of an 8-inch thick concrete wall at noon will enter the interior living space around 8 pm (https://www.energy.gov/energysaver/energy-efficient-home-design/passive-solar-home-design).

3.3. Isolated Gain Systems - Sunspace

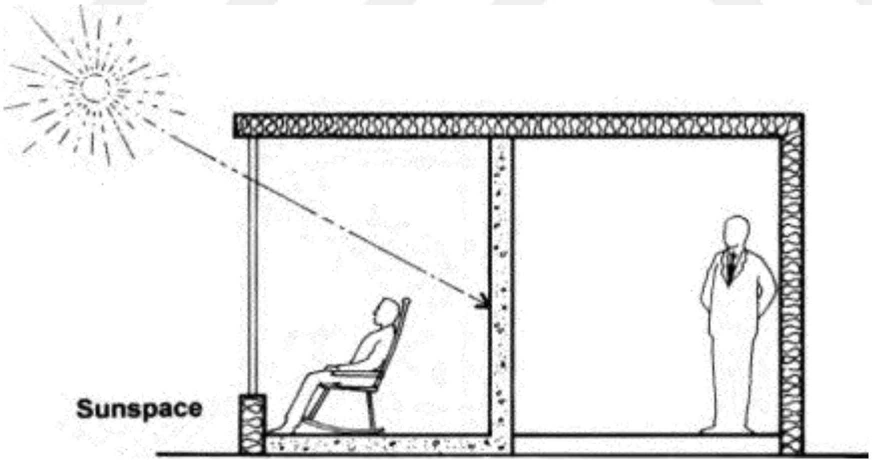


Figure 10 *Section of an isolated gain (Sunspaces) (Lechner, 2015)*

This is a mixture of the direct and indirect system, between the heat store rout and the warming room, visible to the eye through the isolation or physical separation, there is no continuous circulatory ring (Kundakcı, 2004). Sunspaces, also known as passive solar systems, to gain away, is designed to collect heat as the main part of a building, as well as to serve as a secondary living space **in Fig. 10**.

Until recently, this design element is often called a steep greenhouse, however the growing plants are simply an optional function because it is a misleading name. Sunspaces serve three main functions; they provide auxiliary heat, a sunny space to grow plants and a pleasant living area. The design considerations for these three functions are quite different and accommodating all three functions requires compromises. The more appropriate terms, a solarium, solar room or sunroom however the day appears to have become the most common solar rate. The most well-known sunspace houses are owned by Balcomb, the leading researcher in the passive solar systems, is consumed for the common wall of the historic Santa Fe, New Mexico, adobe (Lechner, 2015). In 1978, Balcomb formed the greenhouse heated system by implementing the Trombe wall and the direct winning method. The air in the greenhouses warms up by taking more energy thanks to the Trombe wall. The heated air passes through the venues at the top of the wall. This transition can be made in a natural way, and it can be done with a fan. A water wall can be consumed instead of Trombe wall. The greenhouse reduces heat losses and overheating in the main space by creating a 'buffer zone' between the interior and the outside. The greenhouse should be consumed in motion insulation to prevent the overheating of the type (Balcomb, 1992). The heat store can be turned into an insulated system thanks to an insulation between heat-storied wall, heat storage roof and solar room's and hot room.

Sunspaces has solar heaters along with delightful living spaces. It should be designed as a semi-temperate living space (i.e., neither mechanically heated nor cooled) to keep it a sunspace from being an energy liability (Retrieved from https://www.energy.gov/energysaver/energy-efficient-home-design/passive-solar-home-design Copyright (2019)). Ramakrishnan et al. (2019) The incongruity between energy supply and demand often leads to requirement to store energy as an intermediate step for clean, versatile and efficient use of energy. Among the myriad energy, storage methods, LHTES, natural properties with high volume capacity and energy storage during the process of narrow temperature margins have been found to be a promising method. LHTES methods are based on the solid-liquid phase transition of PCMs that lead to the storage and release of large amounts of thermal energy.

CHAPTER 4

PHASE CHANGE MATERIAL (PCM)

As mentioned before, the climate change caused by global warming is the greatest threat to life in the world. These changes have affected the construction industry. Initially, buildings request more cooling and less heating. The building sector is one of the most important sectors in terms of energy consumption in the world (Skovajsa et al., 2017) Therefore, it is essential to reduce the environmental burden by increasing energy efficiency and reducing energy consumption in the construction industry. Rahimpour et al. (2017) have mentioned that approximately 40% of the total energy consumed in the United States is responsible for residential and commercial buildings. In buildings, about 50% are consumed by HVAC, contributing significantly to global greenhouse gas emissions. In many types of buildings, thermal storage systems are also used to minimize the energy consumption of HVAC equipment, as it is consumed for maximum energy heating and cooling (Lechner, 2015; Rahimpour et al., 2017).

In recent years, as one of the most effective technologies in saving energy resources, many studies have been conducted on these systems actively to reduce energy consumption (Park et al., 2019). Cabeza et al. (2015) have mentioned that thermal energy storage (TES) systems are substances that can store hot or cold for later use under various conditions, such as temperature (Cabeza et al., 2015). Thermal storage plays a significant role in building energy conservation, which is greatly assisted by the incorporation of latent heat storage in building products (Pasupathy and Velraj, 2006). Tatsidjodoung et al. (2013) have mentioned one of the most widely used techniques of sensible heat storage method, which is well known and is the simplest and cheapest way to store energy (Tatsidjodoung et al. (2013). In addition, other energy storage techniques, such as latent heat energy storage and thermochemical energy storage, appear promising considering the large heat storage capacities and/or low heat losses during storage (Tatsidjodoung et al., 2013). TES systems provide better system performance, energy efficiency and low CO_2 emissions (Park et al., 2019) and direct heating-cooling without damaging the ozone layer (Paksoy & Konuklu (2011).

McKenna et al. (2018) have used the TRNSYS plugin for Google SketchUp to handle the potential for geo-cooling and TES systems to reduce the energy and carbon impact of cooling a small commercial building in Mediterranean climate in Marseille, France. By using advanced TES control strategies, 30% more energy savings are possible (McKenna et al., 2018). Paksoy and Konuklu (2011) mentioned that the request for electrical energy is reduced and excessive overload can be prevented in electricity when most needed. Thus, reducing the request for power plants and the consume of fossil fuel provides less pollution solutions (Paksoy & Konuklu, 2011). Ramakrishnan et al. (2019) have mentioned that the use of form stable PCMs in TES applications was an effective method to increase phase stability (Ramakrishnan et al., 2019). PCM provides much higher energy storage densities and heat which is almost stored and released at a stable temperature, dissimilar thermal storage methods (Bruno, 2004). According to Ahmed Gassar and Yun (2017), PCM is a main measure to adapt to climate change in the design and operation stages of a building (Ahmed Gassar and Yun, 2017). Lechner (2015) mentioned that these efficient materials consumed for heat storage are called PCM and store energy in the form of latent heat. In addition, the heat-storage materials have been mentioned in his fourth edition book *"Heating, Cooling, Lighting: Sustainable Design Methods for Architects"* in **Table 7** (Lechner, 2015).

***Table 7** Comparison of Various Heat-Storage Materials (Lechner, 2015)*

Material	Advantages	Disadvantages
Water	- Quite compact - Free	- A storage container is required, which can be expensive - Leakage is possible
Concrete, stone, or brick	- Very stable - Can also serve as wall, floor, etc.	- Expensive to buy and install if only used to store heat
Phase Change Material (PCM)	- Most compact - Can easily fit into frame construction ordinary	- Most expensive

The aim of this chapter is to discuss the types of PCM identification and to address studies with existing types of PCM. As a result, it is also to determine which PCM type is more suitable for work to be done. Indeed, most of these materials are limited to either phase change overall enthalpy or thermal window. Thus, it focuses on the study of PCM, a technology that can be used to increase thermal capacity and which allows definition, properties, classifications and structure's examples.

4.1. What Is PCM?

A PCM is a substance which releases(secretes) or absorbs substantial amounts of thermal energy when it goes through a change in the phase transition, which is solid-liquid to supply useful heating or cooling **in Fig. 11** (https://phasechange.com/technology/; http://www.puretemp.com/stories/understanding-pcms, 2020). When froze(frozen) and/or melted, PCM release and/or absorb heat at specific temperatures (https://phasechange.com/technology/, 2020).

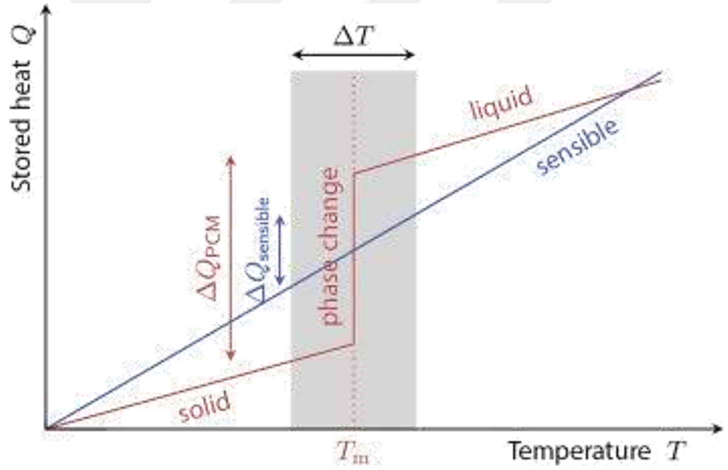


Figure 11 *Physical state of PCM with graphical representation* **(***Günther et al., 2009)*

PCM provides a high heat storage density and has the capability of storing a large amount of heat during the phase change process with a small variation of PCM volume and temperature (Retrieved from https://textilelearner.blogspot.com/2012/10/phase-change-material-pcm.html, 2020). During transitions, when the material changes from one crystal form to another, heat is stored and a small latent heat and small volume changes are observed because there is only a change in the crystal structure (Tatsidjodoung et al. (2013; Rahimpour et al. 2017). Thermal energy is stored as latent heat stored, where the temperature of the storage material varies depending on the amount of energy stored. Alternatively, melting or freezing energy stored when a substance changes from one phase to another. Ice is an example of a 0 °C PCM (Bruno, 2004). Since it has a high impact on both demand shift time and demand reduction, PCM selection should be taken care of according to melting point (Rahimpour et al. 2017).

Comfort conditions and energy savings obtained using PCM on family house, in summer. According to the simulation results based on the evaluation of PCM's effectiveness, it is revealed that comfort temperature conditions can be increased; energy requests and cooling demands can be roughly halved using PCM. The PCM indicates that the night ambient temperature is a significant relevance, as the request to undergo a liquid-solid phase change throughout the night. PCMs happen solid-liquid phase change by absorbing heat and also liquid-solid phase change by releasing heat. If these phase changes occur at temperatures close to thermal comfort temperatures, PCMs can be used as latent heat storage elements, allowing more lighter and more comfortable for buildings (Fernandes and Costa, 2009).

Using PCM is particularly visible in energy consumption for cooling, reducing the interior temperature of buildings in spring-autumn weather conditions (Heim and Clarke 2004), maintaining the value of the range (or close) required by thermal comfort conditions. Nevertheless, to promote liquid-solid phase change throughout the night, some additional cooling effect may be required that can be performed with natural ventilation or assisted cooling systems (Fernandes and Costa, 2009). PCMs can be used in an advantageous way to improve their thermal performance in terms of thermal comfort and reducing energy requires of housing for cooling. A significant amount of energy savings can be achieved by using PCMs with assisted cooling systems. It is not the case in the renewal or strengthening [renewing or retrofitting] of homes where PCMs can make strong contributions to cooling related thermal comfort and energy saving (Fernandes & Costa, 2009).

4.2. Working Principle and Properties

With the emergence of promising recent technologies such as PCM, thermal energy that increases energy efficiency and also allows users to offer network services such as highest demand reduction can provide as storage (Rahimpour et al. 2017).

Park et al. (2019) mentioned that the storage capability of PCM depends on the phase change process that stores and releases thermal energy at a constant temperature (Park et al., 2019). They mentioned that Saffari et al. (2015) examined the optimum PCM melting temperature. The results demonstrated that the best PCM melting point in a cooling-dominant climate was close to maximum of 26 °C and PCM at a low melting point of 20 °C was suitable for heating in dominant climates. Cascone et al. (2018), evaluation of PCMs with different melting temperatures (strengthening variables for the inner or outer side of the opaque envelope, different thicknesses, characteristics of PCM layers, window type, HVAC systems, etc.) in Palermo, Italy did an optimization analysis of the office buildings. As a result, the optimum thermophysical properties of PCMs were found to be affected by the operation. These innovative PCM-based glass systems have evolved the glass curtain wall construction (GCW) system and expanded the market. Park et al. (2019) mentioned that, in the case of US buildings, windows are responsible for a $40 billion loss of energy therefore, it is necessary to examine the application of PCMs to GCW systems as a passive strengthening strategy for energy saving (Park et al., 2019).

The biggest advantage of PCM is that they can store the same amount of energy as a water tank in 4 time less occupied volume (Retrieved from https://www.heat4cool.eu/?page_id=490, 2020). This makes them really practical to install even where space is limited or at premium (Retrieved from https://www.heat4cool.eu/?page_id=490, 2020). According to Hoseinzadeh et al. (2018) one of the most significant advantages of the usage of PCMs, which is effective and useful technologies in the (conservation and retention) protection and storage of thermal energy, is the use of such systems in cooling or heating applications where air is heat transfer fluid (HTF). For the most element, heat transfer rate and efficiency depend on the difference between PCM’s melting temperature and HTF temperature. If certain PCM is consumed, temperature difference between PCM and HTF decreases during the flow direction, in which case the temperature difference between them can be maintained (Hoseinzadeh et al. 2018).

Mazzeo et al. (2017) developed a new procedure for the determining the thermal conductivity and the specific heat in the liquid and solid phase, of the latent heat and of the phase change temperature with a limited number of tests in an experimental device (Mazzeo et al., 2017). Mazzeo et al. (2017) mentioned that according to the manufacturer, PCM presents consistent and repeatable performance over thousands of thermal (melting/solidify) cycles; it is 100% renewable, non-toxic and biodegradable since it is produced from natural agricultural sources (such as palm oil, palm kernel oil, rapeseed oil, coconut oil, and soybean oil). It does not undergo phase segregation and supercooling, the phenomenon in which a substance cools below its freezing point without solidifying (Mazzeo et al. 2017). Mazzeo et al. (2017) The maximum total energy stored is recorded between the two temperature boundary conditions. The reduction of the period gives rise to a reduction of the total stored energy (Mazzeo et al., 2017). The latent heat is the heat that the substance receives or receives from the environment during phase change. The storage volume required for the latent heat storage methods is smaller than the sensible heat (Paksoy and Konuklu (2011).

Tatsidjodoung et al., 2013 claimed that the most important properties of PCM are the melting temperature (which should be in the operating range), substantial latent heat and high thermal conductivity in order to store or release heat. However, the majority of PCMs does not satisfy either of the last two conditions (Tatsidjodoung et al., 2013). Ahmed Gassar and Yun (2017) PCMs are a unique alternative to improving energy efficiency and increasing thermal comfort in buildings. They can be incorporated into building envelopes in different ways to ensure passive heating and cooling. In this context, a passive PCM system is a sustainable way to improve passenger comfort and energy performance, especially in winter and summer weather conditions (Ahmed Gassar and Yun, 2017).

Generally, latent heat storage systems have many advantages over sensible heat storage systems. The performance of latent heat storage systems depends on the thermophysical characteristics of PCMs. However, there are disadvantages associated with latent heat storage materials. There are also some limitations on low thermal conductivity, several cycles, phase separation, subcooling and cost (Tatsidjodoung et al., 2013).

4.3. Classification of PCM

Based on phase change state, PCM’s are classified into three groups: solid-solid PCM, solid-liquid PCM and liquid-gas PCM. Among all, the solid-liquid PCM is the most suitable for thermal energy storage (textilelearner.blogspot.com › 2012/10 › phase-change-material-pcm). PCM can be classified into the following major categories that are solid-liquid PCM comprise: inorganic PCM, organic PCM, and eutectic PCM as shown **in Fig. 12**. Each of these groups has its typical range of melting temperature and melting enthalpy (Tatsidjodoung et al., 2013).

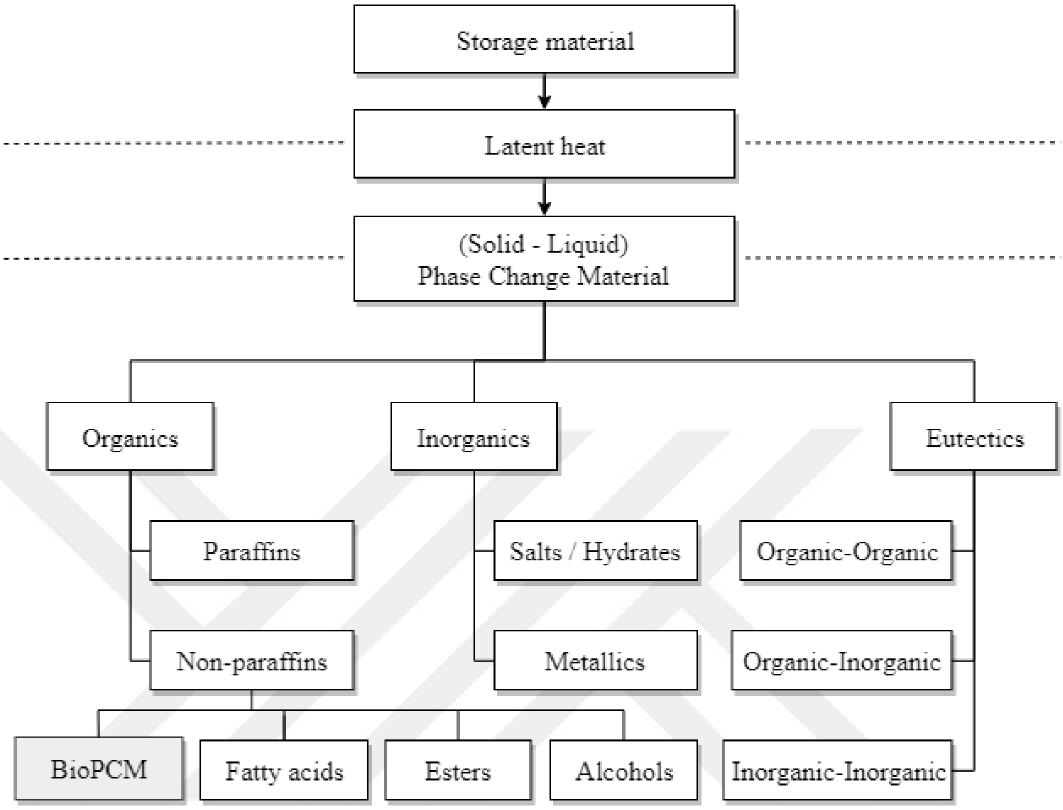


Figure 12 *Classification of PCMs (Tatsidjodoung et al., 2013; Bruno et al., 2015; Bhamare, Rathod and Banerjee, 2019)*

Bruno (2004) has mentioned that organic and inorganic compounds are two most common groups of PCMs. Most organic PCMs such as paraffin demonstrate little or no supercooling properties (that is, do not request to be cooled below their freezing point to initiate crystallization) have a high latent heat per unit weight and are recyclable. Inorganic compounds such as salt hydrates, they are corrosive to most metals and suffer from decomposition and supercooling, which can affect properties of their phase change. Nucleating and thickening agents be capable of added to inorganic PCM to reduce super cooling and decomposition (Bruno, 2004). Patil et al. (2012) mentioned that using PCM’s for storage of latent heat is extremely economical, as the cost for air conditioning systems (installation and running cost) can be significantly reduced. In this framework, PCM could be a smart way to ensure indoor comfort conditions and to reduce building energy consumption by exploiting LHTES, being characterized by a high energy storage density. PCM is in fact able to absorb and release a high amount of latent heat during the phase transition, occurring in a narrow temperature range (Forzano et al. (2019).

According to Paksoy and Konuklu (2011), making the PCM used in applications to be ideal, they must have a high latent heat, high thermal conductivity, high specific heat capacity and small volume change. It should also not be corrosive and toxic and should not show the ability to absorb. PCM used for building applications should melt around 20 °C (Paksoy & Konuklu (2011). In contrast, solid-solid phase change materials offer advantages with less strict container requirements and more design flexibility (Tatsidjodoung et al., 2013). Moreover, solid-liquid PCM can store relatively large amounts of heat in a narrow temperature range without a large volume change and have also proved themselves economically (Tatsidjodoung et al., 2013).

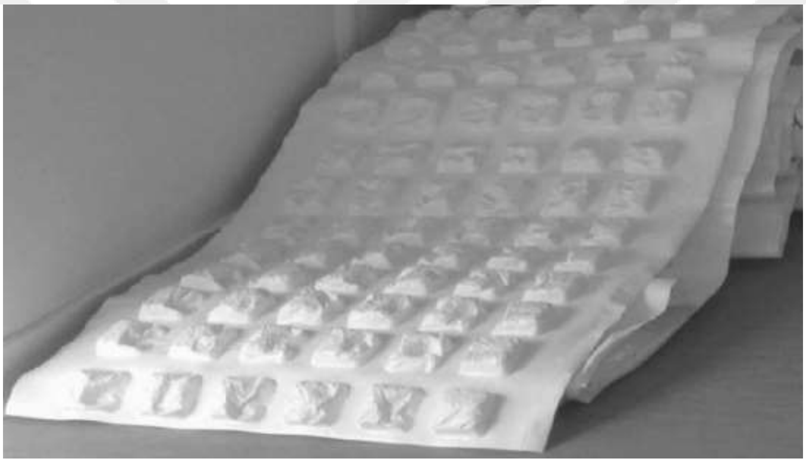


Figure 13 *BioPCM mat (taken from DesignBuilder Software)*

One such product is BioPCM, as shown **in Fig. 13**. A BioPCM is an untested phase change material (made from purely natural sources such as soy and palm) soy-based chemicals with its biobased, biodegradable BioPCM mats (Retrieved from https://www.buildinggreen.com/product-review/biopcm-finally-low-cost-practical-phase-change-material, Copyright 2020) that change from liquid to solid and repeatedly at different temperatures allow the material to absorb and release heat (Retrieved from https://www.treehugger.com/green-architecture/bio-based-phase-changing-material-adds-instant-thermal-mass.html, Copyright 2020) developed by Phase Change Energy Solutions as a result of long- running research and testing. BioPCM is produced using sustainably grown, food grade by-products that is non-toxic and non-corrosive. It has been developed to reduce HVAC stress, eventually providing a more comfortable environment; savings energy and carbon (Retrieved from https://phasechange.com/technology/). BioPCM is not insulation that works by increasing the thermal mass of a building, therefore this product (Retrieved from https://www.architectmagazine.com/technology/products/phase-change-energy-solutions-biopcm_o, Copyright 2020) increasing the time it takes for the structure of a building to warm up or cool down. The product is designed to help keep a structure at a prescribed temperature. According to these information, advantages and disadvantages of PCM classification were shown **in Table 8**.

Table 8 *Comparison of different kinds of PCMs (Retrieved from https://textilelearner.blogspot.com/2012/10/phase-change-material-pcm.html, Copyright 2020; Bruno, 2004; https://phasechange.com/technology/, 2020)*

Classification	Advantages	Disadvantages
Organic PCMs	- Availability in a large temperature range - High latent heat per unit weight - Little or no supercooling properties (that is, do not required be cooled below their freezing point to initiate crystallization) - Chemically stable, recyclable and non-corrosive - Good compatibility with other building materials	- Low thermal conductivity (around 0,2 W/m·K) - High-volume changes during phase change - Flammability
BioPCM	- Non-toxic and non-corrosive - Using sustainably grown plant-based products - Quick and easy installation - Reduce carbon footprint while increasing occupant comfort - Adds resilience to HVAC systems - Requires no power and no maintenance - Useful lifetime of more than 100 years	- It works as a thermal mass; therefore, it increases time it takes for a building's structure to warm or cool down.
Inorganic PCMs	- High latent heat per unit volume of fusion - High thermal conductivity (around 0,5 W/m·K) - Low volume changes during phase change - Availability in low cost - Non-flammable, not poisonous - Potentially, they can be recycled after their useful life.	- Corrosive to most metals and suffer from decomposition and supercooling, which can affect their phase change properties.
Eutectics PCMs	- Sharp melting temperature - High volumetric thermal storage density	- Lack of currently available test data of thermo-physical properties

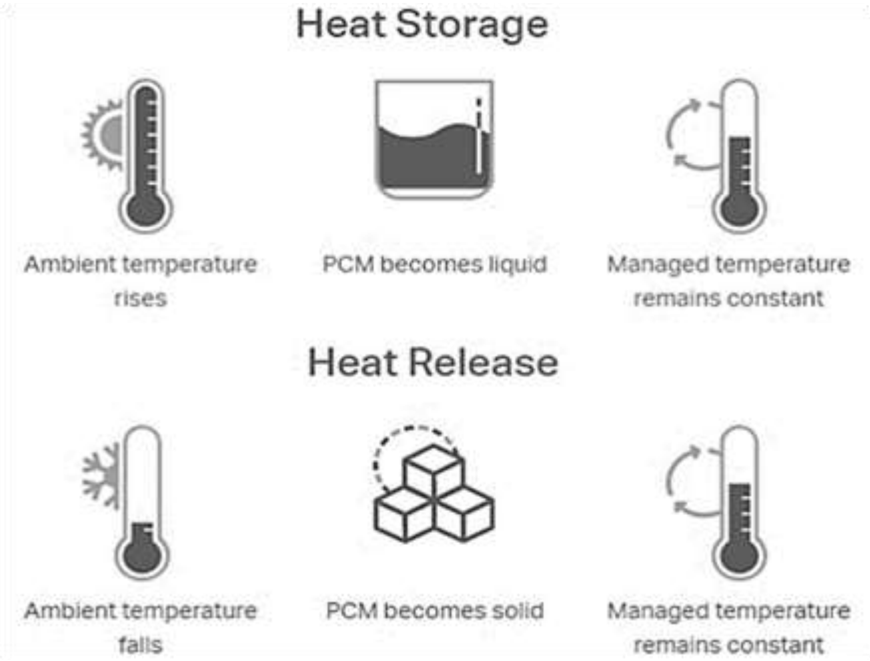


Figure 14 *How BioPCM Works (Retrieved from https://phasechange.com/technology/, Copyright 2020)*

As seen in (Figure 14), when ambient temperatures rise, BioPCM continues to absorb vast amounts of heat without a significant increase in temperature until the material is transformed into a liquid state. When BioPCM reaches the melting point, it absorbs vast amounts of heat and thus cools the area in which it is located. When ambient temperatures drop, BioPCM solidifies and releases stored latent heat to environment (Retrieved from https://phasechange.com/technology/, Copyright 2020). Thermal mass equalizes temperatures between day and night, so this is a small way to store heat. BioPCM does the same however works without mass. Studies demonstrate that heating and cooling costs can be reduced by up to 30%.

4.4. Examples of Structures With PCM

Thermal effect has been evaluated and as a result, PCMs that have been achieved to have a melting point ranging from 10 to 30 ℃ are suitable for cooling and a melting point ranging from 30 to 100 ℃ are suitable for heating (Tatsidjodoung et al., 2013). Residential and commercial buildings consume approximately 60% of the world's electricity, while Europe's residential sector requires 27% of total energy (Tatsidjodoung et al., 2013). Therefore, the main purpose of the using latent heat storage systems for residential applications is to reduce temperature fluctuation, especially as proven in various numerical studies, due to the intensity of solar radiation loads (Ascione et al., 2016). With the PCM application used in buildings, many studies have been performed on energy performance and thermal comfort analysis.

Pasupathy and Velraj (2006) have said that PCM is attractive due to latent heat storage, with small temperature swing release and high storage density. Increasing the thermal storage capacity of a building can increase human comfort by decreasing the frequency of indoor air temperature swings so that the indoor air temperature is closer to the desired temperature for a longer period. With the use of a thermal storage system that includes two different PCMs, it can reduce the air conditioning capacity required and the air conditioning’s cost for a residence. If used on a large scale, it can help with a 50% shift of air conditioning loads during cold and hot seasons (Pasupathy & Velraj, 2006).

Cabeza et al. (2007) have mentioned using concrete walls powered by microencapsulated PCM, the building's interior temperature is 1 °C lower than that of the PCM-free building with experimental results. Seong and Lim (2013) have informed that peak heating and cooling loads for building reduced depending on the type of PCM used and phase change temperature of this. Saffari et al. (2015) have examined application of PCM with high melting point to building envelope models and explained that they improved heating - cooling energy performance and saving high energy. Sage-Lauck et al. (2015) have stated that the use of PCMs in a passive house would significantly reduce overheating hours in a particular area, thereby increasing thermal comfort, reducing overheating in summer.

Marin et al. (2016) have found that the ideal melting temperature for PCM used indoors is affected by the indoor air temperature, while the ideal melting temperatures for outdoor PCMs are affected by the outdoor air temperature. The passive PCM heating and cooling system is a sustainable way to provide thermal comfort and reduce demand for heating and cooling in buildings. The study in Chile assessed the impact on energy performance in light buildings where PCMs could be replaced in different weather conditions. These results have shown that the potential of energy saving in tropical and snow climate regions is limited and acceptable in arid and warm temperate climates (Marin et al., 2016). Souayfane et al., (2016) mentioned that energy savings caused by the application of PCMs to light steel-framed buildings in EU climates; these results demonstrate that applying PCMs to walls improve energy performance in all EU climates (Souayfane et al., 2016). Its proper use of PCM in the envelope can decrease cooling loads and allow comfortable indoor temperature due to smaller indoor temperature fluctuations. This article provides an overview of different PCM applications in buildings and factors affecting the successful and effective use of PCM to reduce cooling loads in different climatic conditions.

Ascione et al. (2016) have discussed design criteria for a small residential building located in Madrid (Spain), Nice (France) Naples (Italy) and Athens (Greece). In their study, optimization techniques, coupled with building performance simulation tools, are used to study the best trade-off among transparent envelope solutions, thermal mass of the building and radiative characteristics of roof. According to these results, it allows to evidence that it is difficult to understand the best equilibrium between summer and winter performance in the Mediterranean climate (Ascione et al., 2016). According to the results of the final analysis, which is related to the integration of the PCM as the finishing layer of the walls, the adoption of the melting temperature of 25 ℃ in the interior has reduces demand for cooling in each city (from 2% in Madrid to 13% in Naples) demonstrates that it allows (Ascione et al., 2016).

Skovajsa et al. (2017) have dealt with the design and usage of a special accumulation device, which is composed of thermal panels based on PCMs. The calculations confirm that the building increases its thermal capacity and is possible to use it for active heating and cooling. Based on these facts arise new trends in the design of energy systems in buildings that are based on the current development of technology and legislative requirements. In addition, the energy consumption of HVAC systems is increasing due to increased demand for thermal comfort. This problem can be solved by using thermal energy storage. Skovajsa et al. (2017) have offered PCMs to optimize thermal energy storage parameters in buildings and achieve better thermal comfort within buildings (Skovajsa et al., 2017). It is quite evident from preceding reviews that the thermal improvements in a building due to inclusion of PCMs depend on the melting temperature of the PCM, type of PCM, the percentage of PCM mixed with conventional material, the climate, design and orientation of the construction of the building.

Responding to a need for sustainable buildings that are flood-proof, DeltaSync is becoming an expert in floating urbanization. With a mission “to design and develop the first self-sufficient floating city in the world,” they are working with PublicDomain

Architects and the City of Rotterdam to build the Floating Pavilion, which has been constructed by Dura Vermeer and is now The Netherlands' largest public floating structure. DeltaSync is focusing their efforts on developing solutions to solve problems of water, climate control, and electricity needs with sensitivity to social dynamics and spatial integration. The Rotterdam Climate Initiative aims to improve the climate to benefit the environment, people, and the economy by collaborating with citizens, government, companies, organizations, and knowledge institutes and reduce CO_2 emissions by 50% and become the "World Capital of CO_2 - free energy." To that end, the City of Rotterdam is building floating structures, the first of which is the Floating Pavilion. Appearing as if they are floating spheres, the three connecting structures of the Pavilion are climate-proof and sustainable. As water levels rise, the pavilion rises, too. Sustainability is achieved by the use of materials, the flexibility of the structure, and its fittings. Solar energy and surface water are utilized in HVAC systems and climatic zones direct energy where it is needed.

Figure 15 *Conference room in Floating ball of Rotterdam, Netherland (Retrieved from https://thegreentake.wordpress.com/tag/stadshavens-rotterdam/, Copyright 2020)*

In the conference room, lectures and meetings are organized for maximum 150 people in **Fig. 15**. This room is heated, when used, to a comfortable temperature, by using the warmth of the thermal connectors that are placed on the roof, as well as the PCM in the walls. These materials absorb warmth (liquid phase) above 21 °C or heath up the room when the temperature is below 21 °C (fixed phase). Conclusion: Improves thermal comfort levels and obviate or reduce the need for air-conditioning. Reduction in peak temperatures is possible. Used in Residential buildings too. Significant advantages for both commercial and residential buildings. Night ventilation- an integral part. Likely to become a valuable tool for improving thermal comfort in domestic buildings.

- PCMs are a unique alternative to improving energy efficiency and improving thermal comfort in buildings. It can be incorporated into building envelopes in different ways to ensure passive heating and cooling.
- These studies will help to find the suitable PCM for various applications, different techniques for the measurement of thermo-physical properties of PCM, suitable heat exchanger with ways to enhance the heat transfer and provide the various designs to store the heat using PCM for different applications i.e. Heating, cooling systems.
- It is quite evident from preceding reviews that the thermal improvements in a building due to inclusion of PCMs depend on the melting temperature of the PCM, type of PCM, the percentage of PCM mixed with conventional material, the climate, design and orientation of the construction of the building.
- A review of PCM applications, and factors affecting the effectiveness of PCM were discussed in this section. The use of PCM in buildings appears very useful; PCM can reduce energy consumption, shift the highest loads of cooling energy demand, reduce temperature waves that provide a heat-comfortable environment and reduce electricity consumption.
- Integrating PCM within the building prevents the inner temperature from increasing thermal comfort. However, PCM applications with many disadvantages are also available. Choosing the most suitable PCM for a particular climate and a specific application was discussed. Melting temperature is the most effective parameter, some authors confirm that high PCM melting temperatures seemed to be more effective for warmer climates, lower PCM melting temperature can be more efficient in colder climates, and others stressed that the importance of selecting PCM melting temperature in the comfort range is then required to test different melting temperatures.

CHAPTER 5

METHODOLOGY

Aforementioned in previous chapters, the research on the use of increased glass structures, passive and active heating systems was conducted as a method of coping with climate change and high energy consumption, and at this point thermal energy storage properties have reached studies on phase change material (PCM). Considering the thermal energy storage systems, PCM is the key focus to handle in terms of concentration and properties to reduce excessive energy consumption.

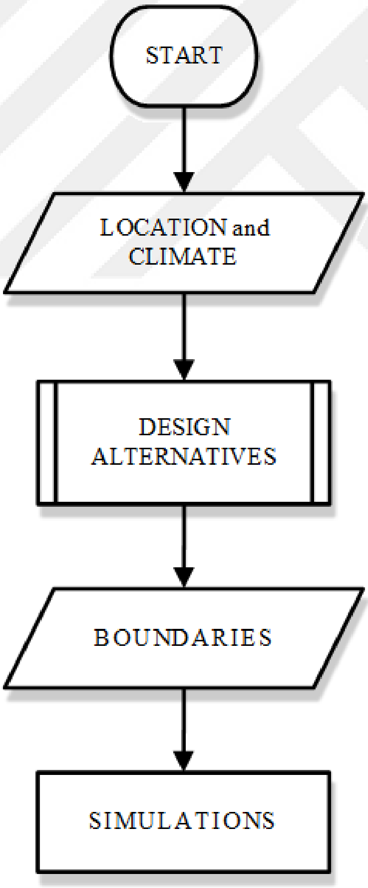


Figure 16 *Flowchart of Methodology*

The flowchart of methodology is seen in **Fig. 16.** In this chapter, a one-story house will be modeled in DesignBuilder tool to investigate the PCM's impacts on the thermal performance. The model was simulated seven times for each of two different climate conditions to compare the significance on the temperature differences.

5.1. Model of Case Study

EnergyPlus (free, open-source and cross-platform-based program, which means it is designed to be used only with computer text [input and output to text files] commands) and Radiance, the most powerful, credible and globally well-respected simulation engines; minimizes error, improves modelling accuracy and provides confidence in results of this unique combination (Retrieved from EnergyPlus: https://energyplus.net/; DesignBuilder: https://designbuilder.co.uk/ 2020). DesignBuilder is an EnergyPlus based software and includes advanced modeling tools with its infrastructure to calculate annual energy consumption, indoor temperature of building and HVAC load. It is useful to minimize energy consumption, carbon emissions (CO_2 emissions) and costs then to optimize solutions to achieve design aims for architects, engineers, building services workers, energy consultants and related departments of universities (Retrieved from DesignBuilder: https://designbuilder.co.uk/; Altensis: https://www.altensis.com/en/services/designbuilder-software/, 2020).

Model was created and simulated in **DesignBuilder** and **EnergyPlus** because they are user-friendly together with graphical user-interfaces. The model description and values are provided **in Table 9**.

Table 9 *Model Description Table*

MODEL DESCRIPTION	MODEL VALUES	
Content of Model Dimensions	Room 10 m x 20 m	Attached greenhouse structure 4 m x 20 m
Floor height	4 m	4 m (ridge height)
Floor area	200 m^2	80 m^2
Type of inter-space wall Dimensions	Concrete wall 4 m x 20 m	
Windows dimensions	(2 m x 20 m) or (4 m x 20 m)	
Windows to wall ratio	50% or 100%	
Glazing type	Single glazing: Sgl Clr 6 mm	

Type of thermodynamic process	non-adiabatic (Inter-space wall)	
	adiabatic (except Inter-space wall)	non-adiabatic (adjacent to ground)

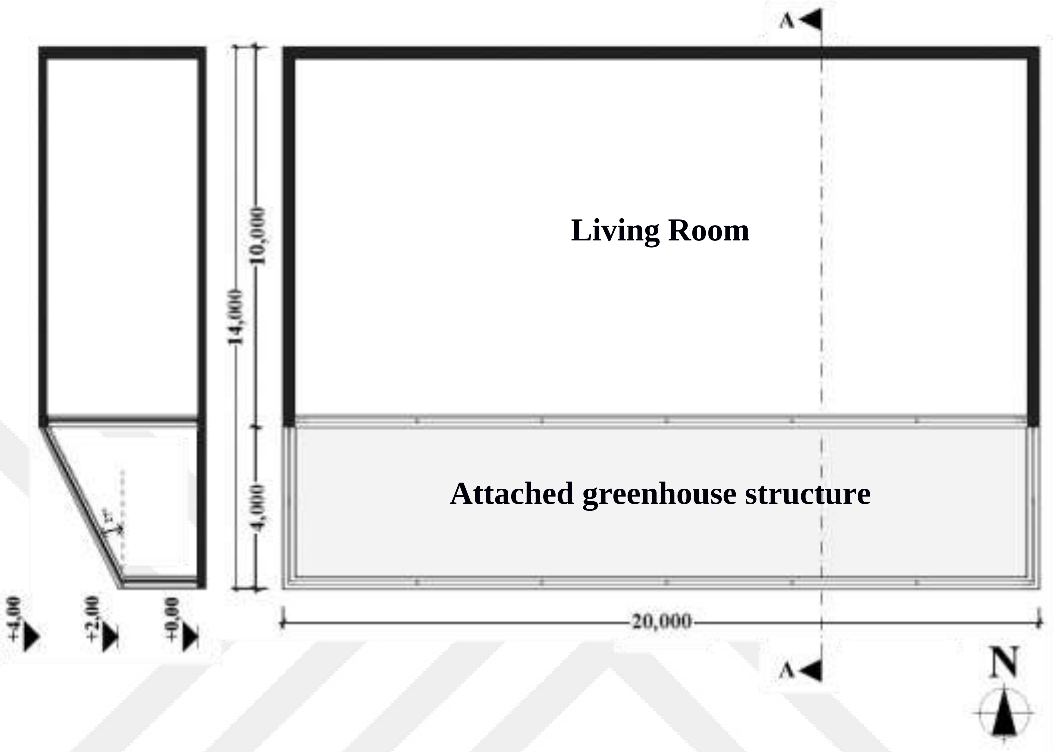


Figure 17 Section and Plan of Base model

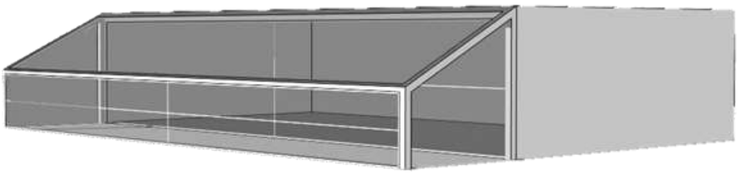


Figure 18 Perspective review of Base model

The base model’s section and plan are seen in **Fig. 17**. The base model’s perspective view is seen in **Fig. 18**. For material details, the section of “Design Alternatives” is verified. The wall that the greenhouse structure integrated with living room is termed as inter-space wall. The inter-space wall is fully window wall in the base model.

5.2. Location and Climate

Figure 19 *Showing the study locations on the map*

In this study, the thermal performance analysis has been performed based on the variables in the model are defined in locations of two different climatic zones: Luxor, Erzurum **in Fig. 19.** The climate, latitude, longitude and elevation of the locations are reached **in Table 10.** Climate data that is not included in the DesignBuilder has been added to program as an epw file.

Table 10 *Climate classification and Geographical summary of the selected locations (Retrieved from DesignBuilder data)*

LOCATION	Climate	Latitude (º)	Longitude (º)	Elevation (m)
Luxor, Egypt	Hot-dry (BWh)	25,67 N	32,70 E	99
Erzurum, Turkey	Cold-humid (Dsb)	39,95 N	41,17 E	1758

Luxor in Egypt, which has a hot and dry climate zone, has been chosen due to the temperature increase caused by global warming **in Fig. 19.** There is not any time difference between Egypt and Turkey. The two seasons are observed in Egypt. The winter is not harsh, however it is rather warmer. The climate data of the Luxor, Egypt has been used in DesignBuilder software. According to Köppen and Geiger classification, this climate is classified as “BWh” (arid, desert, hot arid) (https://www.weatherbase.com/). As seen in **(Figure 20),** the temperature rises to 41 °C in the summer and drops to 6 °C in the winter. The temperature differences of month in the country are also quite high. The average temperature for the year in Luxor is 24 °C. The coldest month on average is January with an average temperature of 14 °C and the hottest month on average is July with an average temperature of 32,5 °C followed by 32 °C in June. Most rain just reported with 30 mm of rainfall is in October (https://www.weatherbase.com/).

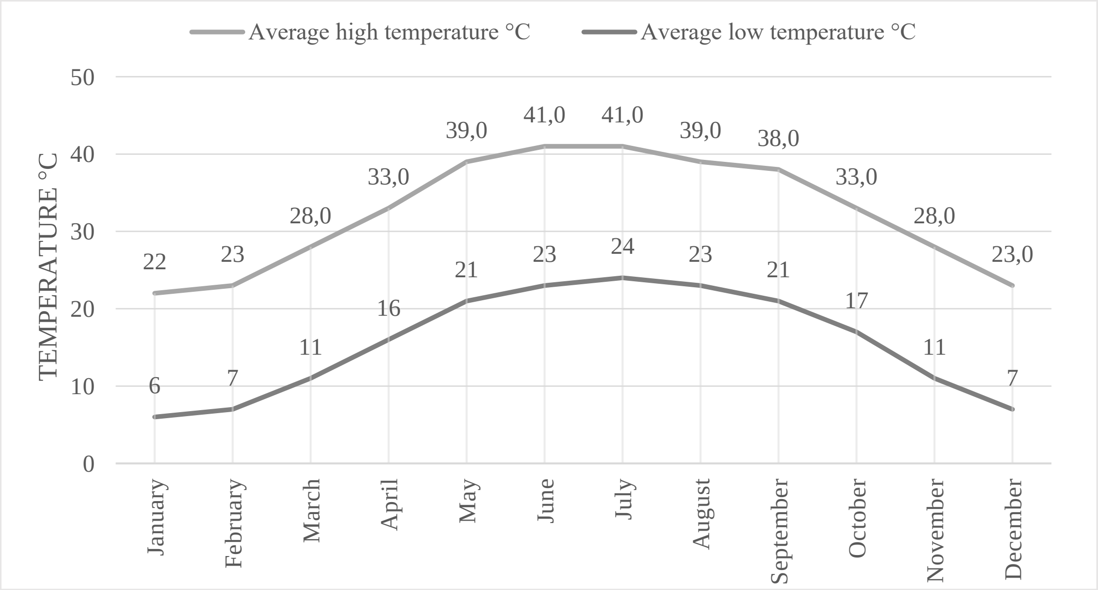


Figure 20 *Monthly Average Temperature in Luxor [potential values for 2020] (Retrieved from https://www.holiday-weather.com/, Copyright 2019).*

Erzurum was chosen as the location for cold and humid climate from Turkey's Eastern Anatolia region **in Fig. 19.** The climate data of the Erzurum was used in DesignBuilder software. According to Köppen and Geiger classification, this climate is classified as "Dfb" (snow, fully humid, warm summer) (https://www.weatherbase.com/). In the Erzurum, the summers are warm and clear with the temperature rises to 27,2 °C; while the winters are quite cold, snowy and cloudy with the temperature drops to -14 °C **in Fig. 21.** The average temperature for the year in Erzurum is 5,7 °C **in Fig. 21.** As seen in **(Figure 21),** The hottest month is August with an average temperature of 19,2 °C followed by to July with an average temperature of 18,8 °C and the coldest month on average is January, with an average temperature of -9 °C **in Fig. 21.** The average amount of precipitation for the year in Erzurum is 449.6 mm. The month with the most precipitation on average is May with 73.7 mm of precipitation. The month with the least precipitation is August with an average of 17.8 mm (Retrieved from https://www.weatherbase.com/, Copyright 2019).

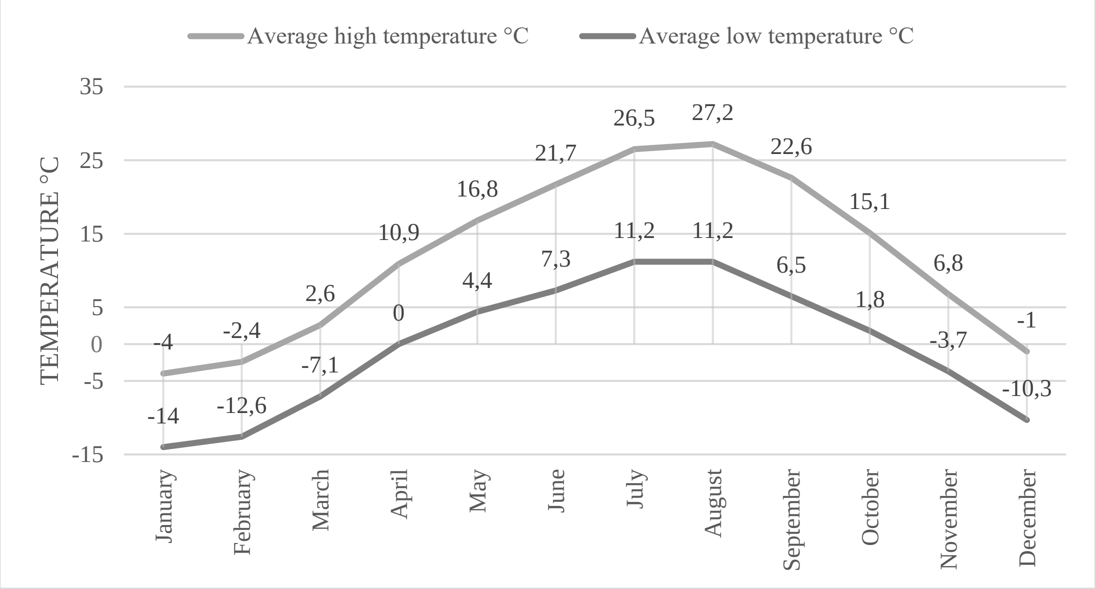


***Figure 21** Monthly Average Temperature in Erzurum [measurement period 1927 - 2018] (Retrieved from https://www.mgm.gov.tr/veridegerlendirme/il-ve-ilceler-istatistik.aspx?k=A&m=ERZURUM, Copyright 2019).*

5.3. Design Alternatives

The model has been iterated for 6 different design samples beside the base model named as Alternative 1. The alternatives have been determined by changing the inter-space wall construction materials as tabulated **in Table 11**. The required material information data was added in the DesignBuilder's material library.

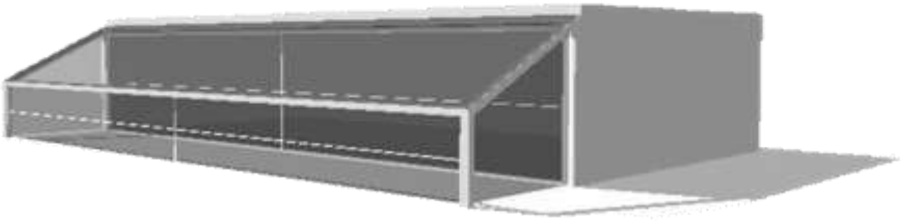


***Figure 22** fully window wall alternative of inter-space wall*

"Fully window wall alternative" has been illustrated in detail representation **in Fig. 22**. In **Table 11**, Alternative 1 materials used from exterior to interior; window glass block in respectively. This alternative's U-value is 2,482 W/m^{2}K.

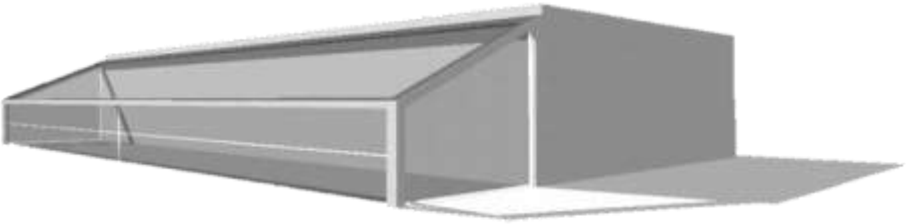


***Figure 23** concrete wall alternatives of inter-space wall*

"Concrete wall alternatives" has been illustrated detail representation **in Fig. 23**. According to **Table 11**, concrete wall alternatives are as follows; Alternative 2 materials used from exterior to interior; gypsum plaster board, reinforced concrete (with 1% steel) and plaster in respectively. This alternative's U-value is 2,398 W/m^{2}K.

Alternative 3 materials used from exterior to interior; gypsum plaster board, reinforced concrete (with 1% steel), BioPCM M182/Q21 and plaster in respectively. This alternative's U-value is 1,269 W/m^{2}K. Alternative 4 materials used from exterior to interior; gypsum plaster board, BioPCM M182/Q21, reinforced concrete (with 1% steel) and plaster in respectively. This alternative's U-value is 1,269 W/m^{2}K.

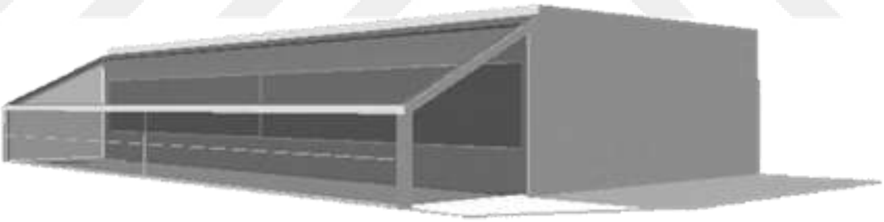


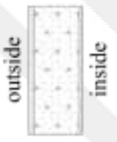
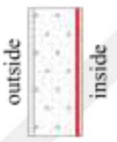
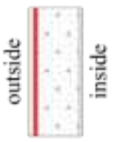
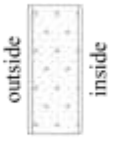
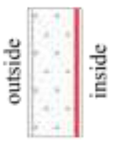
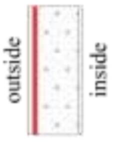
***Figure 24** concrete wall with window alternatives of inter-space wall*

"Win alternatives" has been illustrated detail representation **in Fig. 24**. According to **Table 11**, concrete wall with window alternatives are as follows; Alternative 5 materials used from exterior to interior; gypsum plaster board, reinforced concrete (with 1% steel) and plaster in respectively. This alternative's U-value is 2,398 W/m^{2}K.

Alternative 6 materials used from exterior to interior; gypsum plaster board, reinforced concrete (with 1% steel), BioPCM M182/Q21 and plaster in respectively. This alternative's U-value is 1,269 W/m^{2}K. Alternative 7 materials used from exterior to interior; gypsum plaster board, BioPCM M182/Q21, reinforced concrete (with 1% steel) and plaster in respectively. This alternative's U-value is 1,269 W/m^{2}K.

This material has been selected from the program's library and recorded. According to the decision provide alternatives and material details; changes in the base model have been commenced. Each alternative model has been recorded with a different file name. As seen **in Table 11**, our variables are only the material layer's order, and this order is kept constant for each simulation.

***Table 11** Wall material's layers and values*

MATERIAL LAYER (from exterior to interior)								
Alternatives		**N**	**Material Name**	**λ (W/mK)**	**ρ kg/m³**	**c J/kgK**	**d (m)**	**U-value (W/m²K)**
Alternative 1	 	1	window glass block	0,700	2500	837	0,013	**2,482**
Alternative 2	 	1	gypsum plaster board	0,250	900	1000	0,013	**2,398**
		2	reinforced concrete (with 1% steel)	2,300	2300	1000	0,203	
		3	plaster	0,300	1000	1000	0,005	
Alternative 3		1	gypsum plaster board	0,250	900	1000	0,013	**1,269**
		2	reinforced concrete (with 1% steel)	2,300	2300	1000	0,203	
		3	BioPCM M182/Q21	0,200	235	1970	0,012	
		4	plaster	0,300	1000	1000	0,005	
Alternative 4		1	gypsum plaster board	0,250	900	1000	0,013	**1,269**
		2	BioPCM M182/Q21	0,200	235	1970	0,012	
		3	reinforced concrete (with 1% steel)	2,300	2300	1000	0,203	
		4	plaster	0,300	1000	1000	0,005	
Alternative 5	 	1	gypsum plaster board	0,250	900	1000	0,013	**2,398**
		2	reinforced concrete (with 1% steel)	2,300	2300	1000	0,203	
		3	plaster	0,300	1000	1000	0,005	
Alternative 6		1	gypsum plaster board	0,250	900	1000	0,013	**1,269**
		2	reinforced concrete (with 1% steel)	2,300	2300	1000	0,203	
		3	BioPCM M182/Q21	0,200	235	1970	0,012	
		4	plaster	0,300	1000	1000	0,005	
Alternative 7		1	gypsum plaster board	0,250	900	1000	0,013	**1,269**
		2	BioPCM M182/Q21	0,200	235	1970	0,012	
		3	reinforced concrete (with 1% steel)	2,300	2300	1000	0,203	
		4	plaster	0,300	1000	1000	0,005	

5.4. Boundaries

The boundary conditions for the study are:

- The model has been designed as a basic shoebox rectangle model to iterate the model easily; however, more complex models can be applied within the new material data in the future.
- Considering the simulation time commitment, the model has been applied to only two climates.
- The results have been compared only for the hottest and coldest months chosen as July and January on their 18th day of the month. The hottest and coldest months are available for the two locations in July and January as well as 18th of months.
- Inter-space wall has been chosen as a variable system that is consisting of material details. These material details are with and without window, fully window, without and inside or outside PCM.

All simulations have been made and simulation datas have been obtained separately for each location has been recorded. In this way, the annual results have been obtained for each alternatives. As simulation outputs, outdoor air temperature (T_{out}), indoor air temperature (T_{in}), inter-space air temperature ($T_{inter\text{-}space}$) and energy loses-gains (solar, glazing or wall) have been reached and these are on a per hour basis. It is also possible to evaluate these data by saving as an Excel file that is out of hourly (monthly or regularly).

One of the main objectives of the simulations is how the structure reacts in different climates, while the other is related to the applicability of the PCM. In the first section of the chapter, the basic model has been defined. The second section provides information about climate types and locations. Accordingly, 2 different climate types have been observed, Luxor hot-dry climate type and Erzurum cold-humid climate type. In the third section, the inter-space wall’s layer and values have been addressed to their design alternatives and have been discussed as variables. Finally, the simulation limitations have been discussed.

CHAPTER 6

RESULTS AND DISCUSSION

6.1. Simulation Results For Luxor

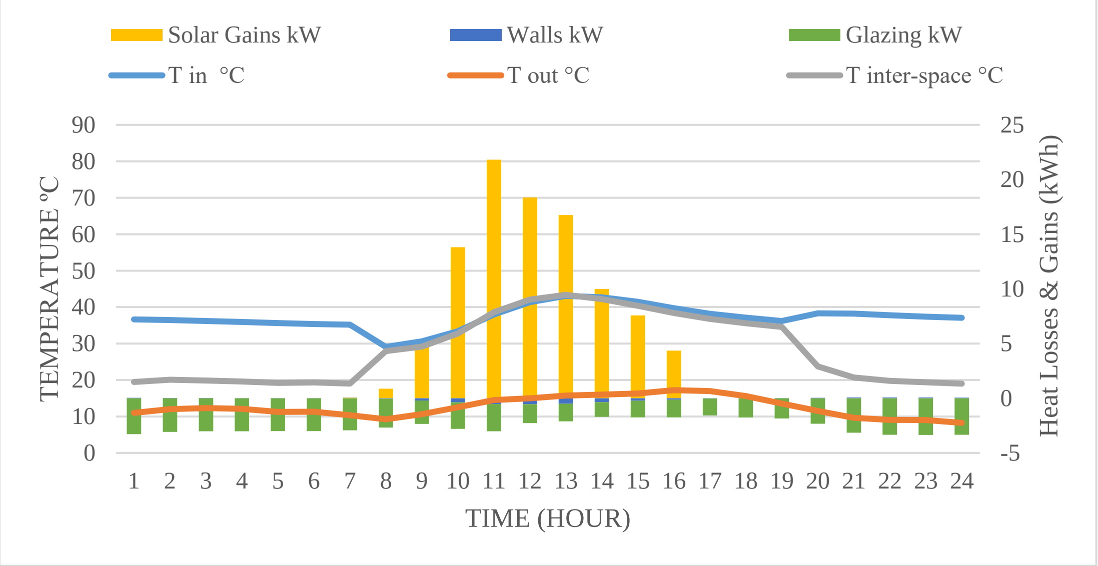


Figure 25 *on 18 January, Alternative 1 in Luxor*

As seen in (Figure 25), the indoor air, the outdoor air and the inter-space air temperatures are on January 18th, 37 ºC; 12,5 ºC and 28 ºC in respectively. The indoor air temperature drops down to 29 ºC at 08:00; after this time the temperature starts to increase up to 43 ºC at 13:00 and then begins to fall again. The outdoor air temperature drops down to 9 ºC at 08:00, starts to increase up to 17 ºC at 16:00 and then begins to fall again and reaches 8 ºC at 24:00. The inter-space air temperature starts to increase up from 07:00 until 13:00, reaches to 43 ºC and then begins to fall.

The solar heat gains start at sunrise and end at sunset. Therefore, the heat gains values start increasing at 07:00, reach their maximum amounts 21,81 kW at 11.00, and drop down to 0 kW at 17.00. For a similar situation, it has been observed that heat losses (walls and glazing) that occurred at any time of the day are caused by the material type of inter-space wall. The wall losses values are close to each other and minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00. The glazing losses values are close to each other and minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00.

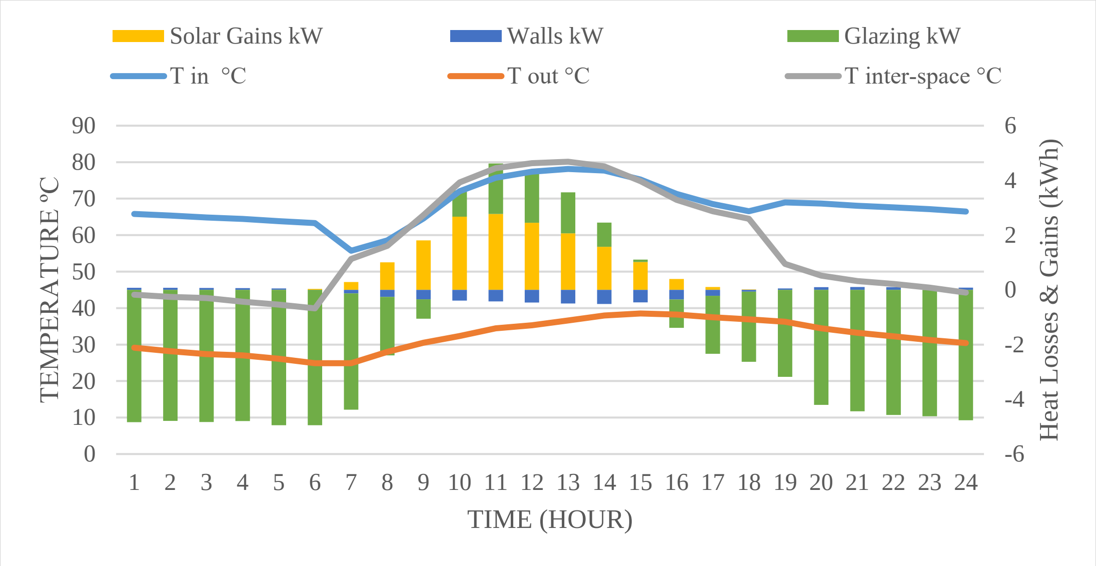


***Figure 26** on 18 July, Alternative 1 in Luxor*

As seen in (Figure 26), the indoor air, the outdoor air and the inter-space air temperatures are on July 18th, 68 ºC; 32 ºC and 57 ºC in respectively. The indoor air temperature drops down to 55 ºC at 07:00; after this time the temperature starts to increase up to 78 ºC at 13:00 and then begins to fall again to 66,5 ºC at 18:00. The outdoor air temperature drops down to 25 ºC at 06:00 – 07:00 in respectively; it starts to increase up to 38,5 ºC at 15:00 and then begins to fall to - 20 ºC at 24:00. The inter-space air temperature starts to increase up to 40 ºC at 06:00, reaches to 80 ºC at 13:00 and then begins to fall.

The solar gains values start increasing at 06:00, reach their maximum amounts 21,81 kW at 11.00, and drop down to 0 at 17.00. The solar gains values are 0,052 kW; 0,868 kW; 4,86 kW; 13,81 kW; 21,81 kW; 18,35 kW; 16,75 kW; 9,98 kW; 7,57 kW and 4,36 kW respectively. The glazing losses values are minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00. The wall losses values are close to each other and minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00.

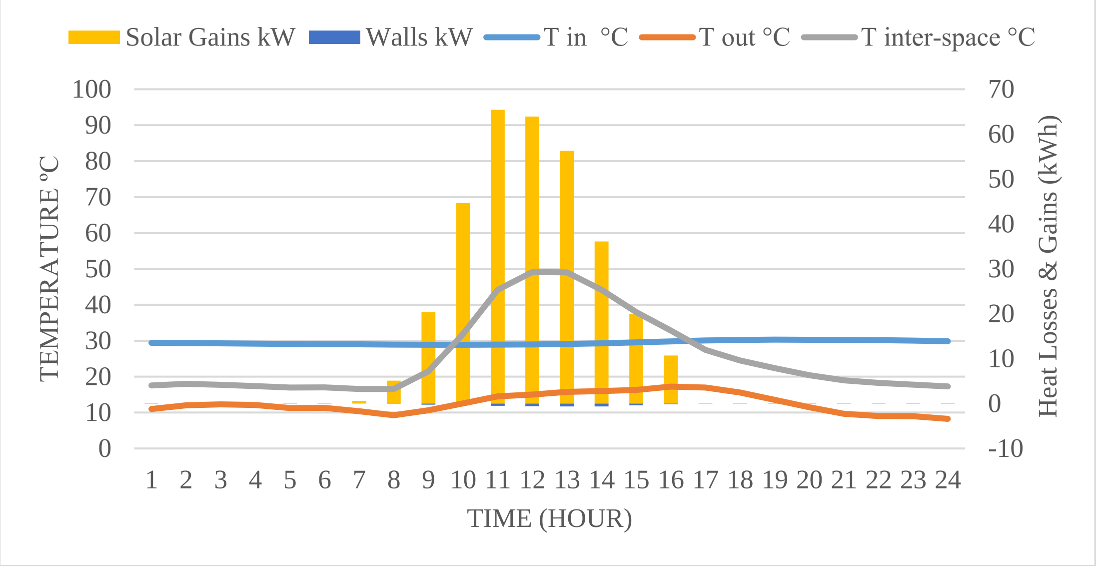


***Figure 27** on 18 January, Alternative 2 in Luxor*

As seen in (Figure 27), the indoor air, the outdoor air and the inter-space air temperatures are on January 18th, 29,5 ºC; 12,5 ºC and 25,6 ºC in respectively. The indoor air temperatures are close to each other and a minimum of 28,8 ºC at 09:00; maximum 30,30 ºC at 19:00. The outdoor air temperature drops down to 9,25 ºC at 08:00; starts to increase up to 17,25 ºC at 16:00 and then begins to fall to 8,25 ºC at 24:00. The inter-space air temperature starts to increase up to 9,25 ºC at 08:00, reaches 49 ºC at 12:00-13:00 and then begins to fall.

The solar gains values start increasing at 07:00, reach their maximum amounts 21,81 kW at 11.00, and drop down to 0 at 17.00. The solar gains values are 0,052 kW; 0,868 kW; 4,86 kW; 13,81 kW; 21,81 kW; 18,35 kW; 16,75 kW; 9,98 kW; 7,57 kW and 4,36 kW respectively. The glazing losses values are minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00. The wall losses values are close to each other and minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00.

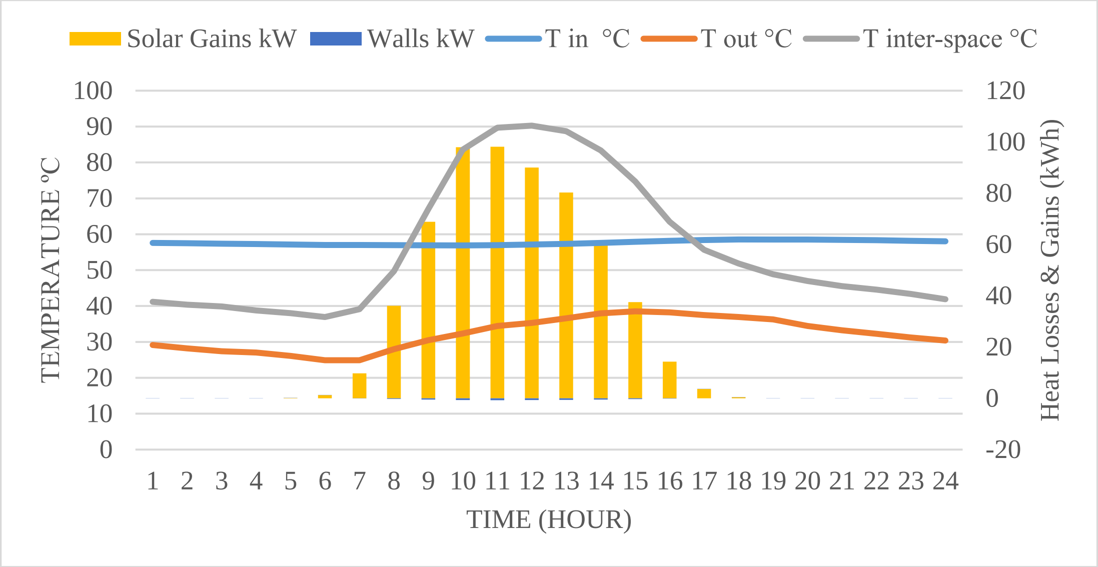


***Figure 28** on 18 July, Alternative 2 in Luxor*

As seen in (Figure 28), the indoor air, the outdoor air and the inter-space air temperatures are on July 18th, 57,65 ºC; 32,16 ºC and 56 ºC in respectively. The indoor air temperatures are close to each other and a minimum of 56,89 ºC at 10:00; a maximum of 58,54 ºC at 18:00. The outdoor air temperature drops down to 25 ºC at 06:00-07:00; starts to increase up to 38,52 ºC at 15:00 and then begins to fall to 30,4 ºC at 24:00. The inter-space air temperature starts to increase to 37 ºC at 06:00, reaches 90,25 ºC at 12:00 and then begins to fall.

The solar gains values start increasing at 07:00, reach their maximum amounts 21,81 kW at 11.00, and drop down to 0 at 17.00. The solar gains values are 0,052 kW; 0,868 kW; 4,86 kW; 13,81 kW; 21,81 kW; 18,35 kW; 16,75 kW; 9,98 kW; 7,57 kW and 4,36 kW respectively. The glazing losses values are minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00. The wall losses values are close to each other and minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00.

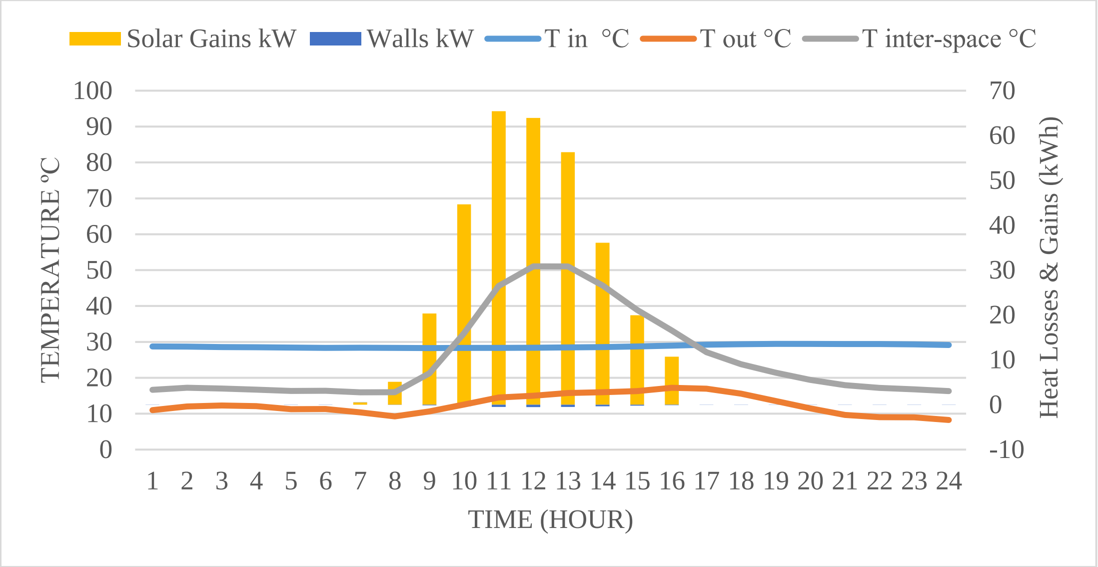


***Figure 29** on 18 January, Alternative 3 in Luxor*

As seen in (Figure 29), the indoor air, the outdoor air and the inter-space air temperatures are on January 18th, 28,78 ºC; 12,54 ºC and 25,48 ºC in respectively. The indoor air temperatures are close to each other and a minimum of 28,28 ºC at 09:00; a maximum of 29,44 ºC at 20:00. The outdoor air temperature drops down to 9,25 ºC at 08:00; starts to increase up to 17,22 ºC at 16:00 and then begins to fall to 08,25 ºC at 24:00. The inter-space air temperature starts to increase to 16(15,95) ºC at 07:00, reaches 51 ºC at 12:00 and then begins to fall.

The solar gains values start increasing at 07:00, reach their maximum amounts 21,81 kW at 11.00, and drop down to 0 at 17.00. The solar gains values are 0,052 kW; 0,868 kW; 4,86 kW; 13,81 kW; 21,81 kW; 18,35 kW; 16,75 kW; 9,98 kW; 7,57 kW and 4,36 kW respectively. The glazing losses values are minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00. The wall losses values are close to each other and minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00.

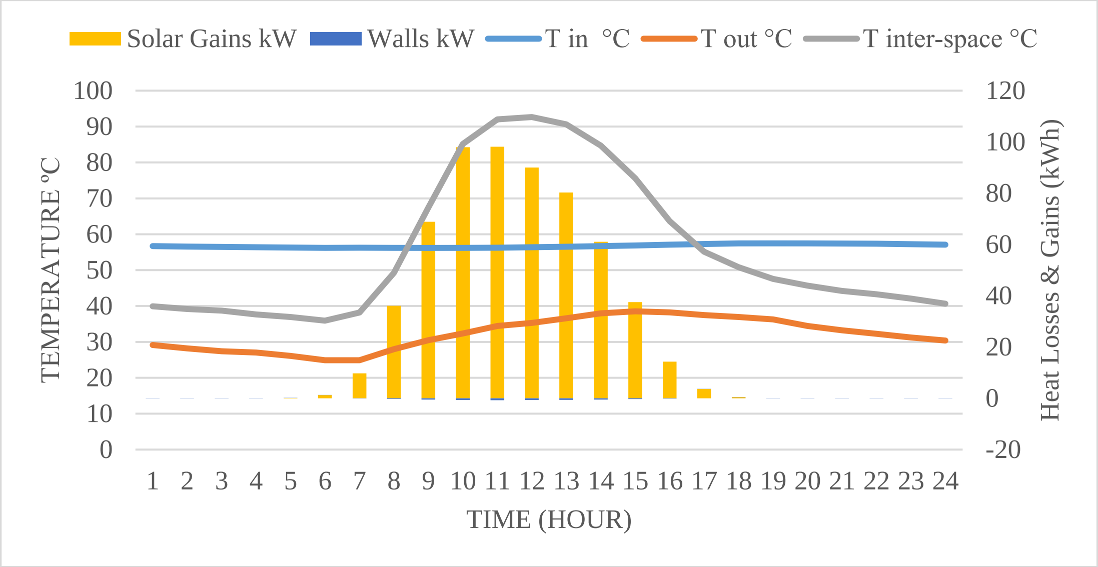


***Figure 30** on 18 July, Alternative 3 in Luxor*

As seen in (Figure 30), the indoor air, the outdoor air and the inter-space air temperatures are on July 18th, 56,74 ºC; 32,16 ºC and 55,71 ºC in respectively. The indoor air temperatures are close to each other and a minimum of 56,18 ºC at 09:00; a maximum of 57,46 ºC at 19:00. The outdoor air temperature drops down to 25(24,9) ºC at 06:00-07:00; starts to increase up to 38,52 ºC at 15:00 and then begins to fall to 30,4 ºC at 24:00. The inter-space air temperature starts to increase to 36(35,92) ºC at 06:00, reaches 92,65 ºC at 12:00 and then begins to fall.

The solar gains values start increasing at 07:00, reach their maximum amounts 21,81 kW at 11.00, and drop down to 0 at 17.00. The solar gains values are 0,052 kW; 0,868 kW; 4,86 kW; 13,81 kW; 21,81 kW; 18,35 kW; 16,75 kW; 9,98 kW; 7,57 kW and 4,36 kW respectively. The glazing losses values are minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00. The wall losses values are close to each other and minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00.

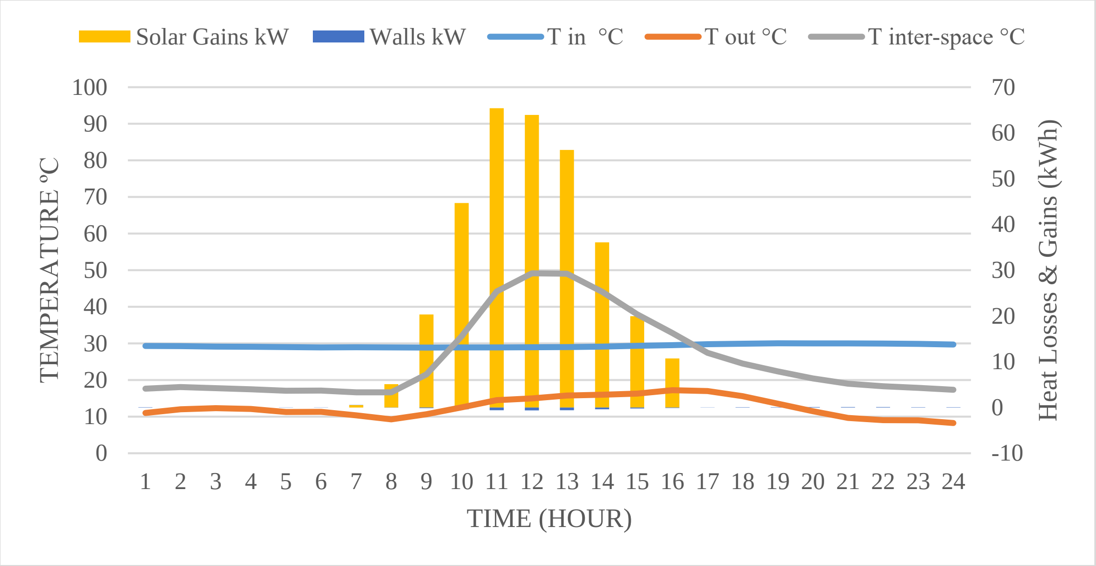


***Figure 31** on 18 January, Alternative 4 in Luxor*

As seen in (Figure 31), the indoor air, the outdoor air and the inter-space air temperatures are on January 18th, 29,35 ºC; 12,54 ºC and 25,68 ºC in respectively. The indoor air temperatures are close to each other and a minimum of 28,86 ºC at 09:00; a maximum of 30,03 ºC at 19:00. The outdoor air temperature drops down to 9,25 ºC at 08:00; starts to increase up to 17,22 ºC at 16:00 and then begins to fall to 8,25 ºC at 24:00. The inter-space air temperature starts to increase in 16,64 ºC at 08:00, reaches 49,15 ºC at 12:00 and then begins to fall.

The solar gains values start increasing at 07:00, reach their maximum amounts 21,81 kW at 11.00, and drop down to 0 at 17.00. The solar gains values are 0,052 kW; 0,868 kW; 4,86 kW; 13,81 kW; 21,81 kW; 18,35 kW; 16,75 kW; 9,98 kW; 7,57 kW and 4,36 kW respectively. The glazing losses values are minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00. The wall losses values are close to each other and minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00.

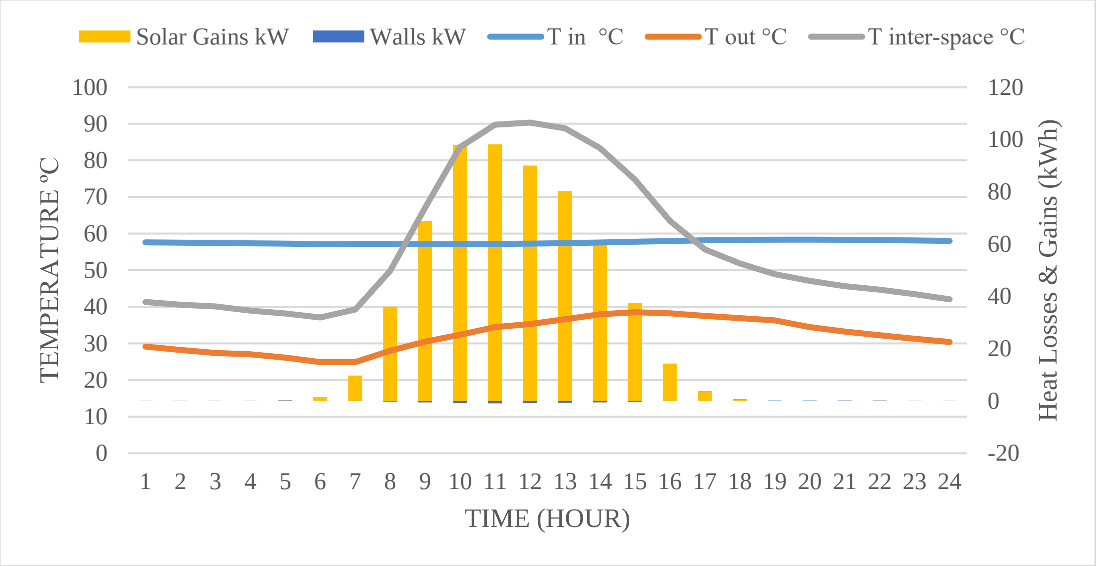


Figure 32 *on 18 July, Alternative 4 in Luxor*

As seen in (Figure 32), the indoor air, the outdoor air and the inter-space air temperatures are on July 18th, 57,65 ºC; 32,16 ºC and 56,07 ºC in respectively. The indoor air temperatures are close to each other and a minimum of 57,12 ºC at 06:00; a maximum of 58,33 ºC at 19:00. The outdoor air temperature drops down to 24,9 ºC at 06:00-07:00; starts to increase up to 38,52 ºC at 15:00 and then begins to fall to 30,4 ºC at 24:00. The inter-space air temperature starts to increase in 37,08 ºC at 06:00, reaches 90,31 ºC at 12:00 and then begins to fall.

The solar gains values start increasing at 07:00, reach their maximum amounts 21,81 kW at 11.00, and drop down to 0 at 17.00. The solar gains values are 0,052 kW; 0,868 kW; 4,86 kW; 13,81 kW; 21,81 kW; 18,35 kW; 16,75 kW; 9,98 kW; 7,57 kW and 4,36 kW respectively. The glazing losses values are minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00. The wall losses values are close to each other and minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00.

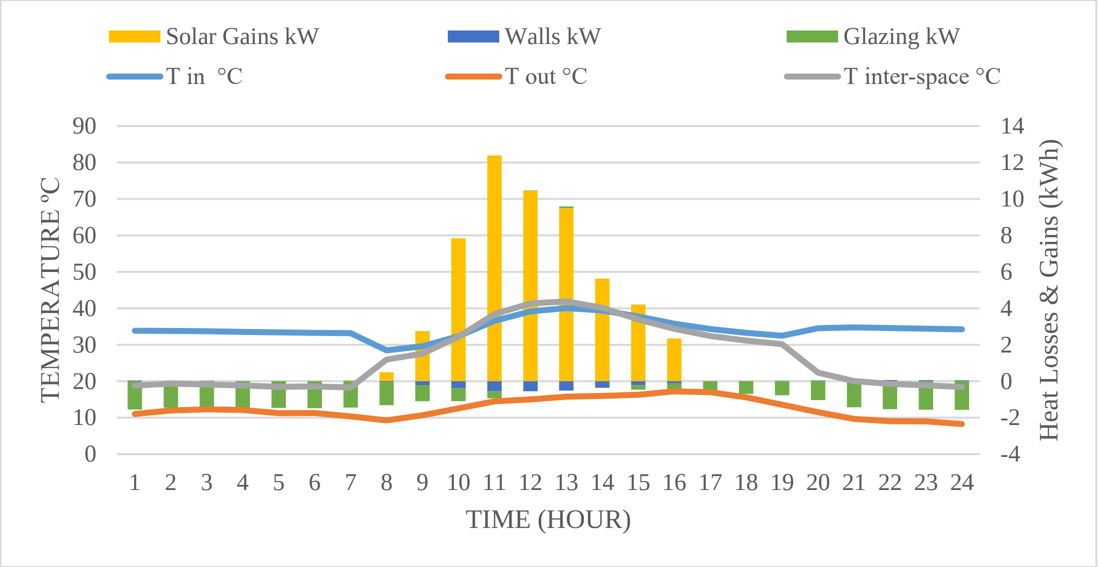


***Figure 33** on 18 January, Alternative 5 in Luxor*

As seen in (Figure 33), the indoor air, the outdoor air and the inter-space air temperatures are on January 18th, 34,44 ºC; 12,54 ºC and 26,79 ºC in respectively. The indoor air temperature drops down to 28,47 ºC at 08:00; after this time the temperature starts to increase up to 40,06 ºC at 13:00 and then begins to fall again to 32,49 ºC at 19:00. The outdoor air temperature drops down to 9,25 ºC at 08:00; starts to increase up to 17,22 ºC at 16:00 and then begins to fall to 8,25 ºC at 24:00. The inter-space air temperature starts to increase in 18,29 ºC at 07:00, reaches 41,88 ºC at 13:00 and then begins to fall.

The solar gains values start increasing at 07:00, reach their maximum amounts 21,81 kW at 11.00, and drop down to 0 at 17.00. The solar gains values are 0,052 kW; 0,868 kW; 4,86 kW; 13,81 kW; 21,81 kW; 18,35 kW; 16,75 kW; 9,98 kW; 7,57 kW and 4,36 kW respectively. The glazing losses values are close to each other and minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00. The wall losses values are close to each other and minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00.

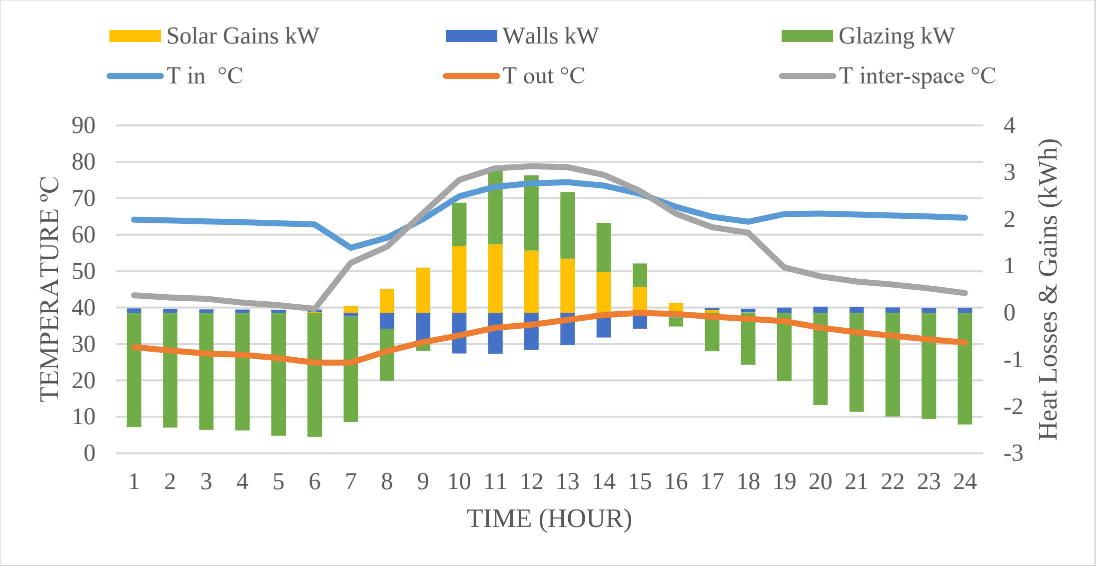


***Figure 34** on 18 July, Alternative 5 in Luxor*

As seen in (Figure 34), the indoor air, the outdoor air and the inter-space air temperatures are on July 18th, 66,08 ºC; 32,16 ºC and 56,45 ºC in respectively. The indoor air temperature drops down to 56,41 ºC at 07:00; after this time the temperature starts to increase up to 74,41 ºC at 13:00 and then begins to fall again to 63,55 ºC at 18:00. The outdoor air temperature drops down to 24,9 ºC at 06:00-07:00; starts to increase up to 38,52 ºC at 15:00 and then begins to fall to 30,4 ºC at 24:00. The inter-space air temperature starts to increase in 39,64 ºC at 06:00, reaches 78,81 ºC at 12:00 and then begins to fall.

The solar gains values start increasing at 07:00, reach their maximum amounts 21,81 kW at 11.00, and drop down to 0 at 17.00. The solar gains values are 0,052 kW; 0,868 kW; 4,86 kW; 13,81 kW; 21,81 kW; 18,35 kW; 16,75 kW; 9,98 kW; 7,57 kW and 4,36 kW respectively. The glazing losses values are minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00.The wall losses values are close to each other and minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00.

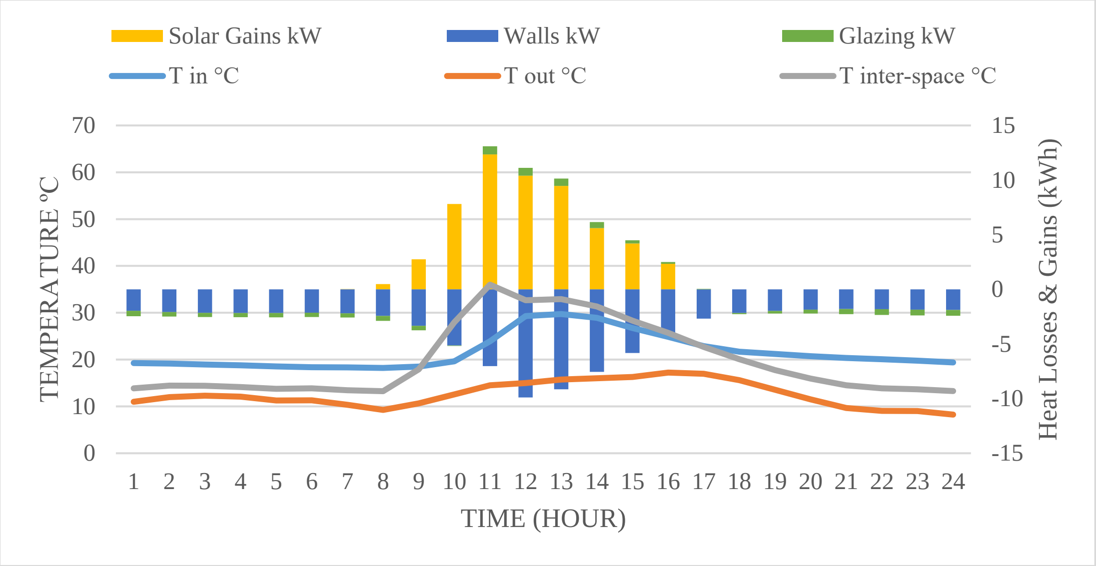


Figure 35 *on 18 January, Alternative 6 in Luxor*

As seen in (Figure 35), the indoor air, the outdoor air and the inter-space air temperatures are on January 18th, 21,55 ºC; 12,54 ºC and 19,82 ºC in respectively. The indoor air temperature drops down to 18,21 ºC at 08:00; after this time the temperature starts to increase up to 29,72 ºC at 13:00 and then begins to fall again to 19,40 ºC at 24:00. The outdoor air temperature drops down to 9,25 ºC at 08:00; starts to increase up to 17,22 ºC at 16:00 and then begins to fall to 8,25 ºC at 24:00. The inter-space air temperature starts to increase in 13,25 ºC at 08:00, reaches 35,99 ºC at 11:00 and then begins to fall.

The solar gains values start increasing at 07:00, reach their maximum amounts 21,81 kW at 11.00, and drop down to 0 at 17.00. The solar gains values are 0,052 kW; 0,868 kW; 4,86 kW; 13,81 kW; 21,81 kW; 18,35 kW; 16,75 kW; 9,98 kW; 7,57 kW and 4,36 kW respectively. The glazing losses values are close to each other and minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00. The wall losses values are close to each other and minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00.

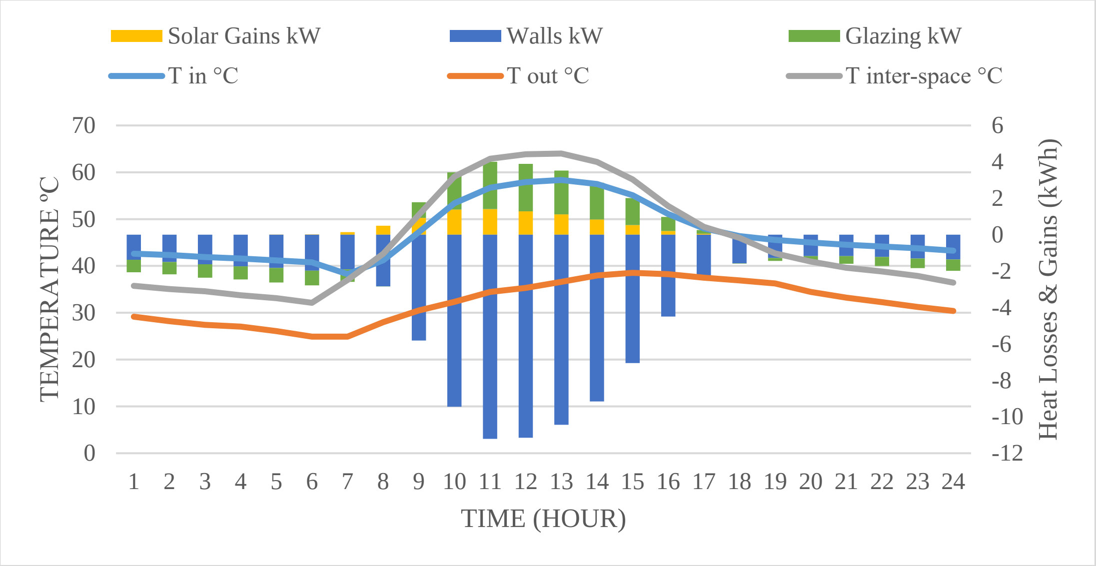


Figure 36 *on 18 July, Alternative 6 in Luxor*

As seen in (Figure 36), the indoor air, the outdoor air and the inter-space air temperatures are on July 18th, 46,98 ºC; 32,16 ºC and 45,37 ºC in respectively. The indoor air temperature drops down to 38,24 ºC at 07:00; after this time the temperature starts to increase up to 58,35 ºC at 13:00 and then begins to fall again to 43,25 ºC at 24:00. The outdoor air temperature drops down to 24,9 ºC at 06:00-07:00; starts to increase up to 38,52 ºC at 15:00 and then begins to fall to 30,4 ºC at 24:00. The inter-space air temperature starts to increase in 32,12 ºC at 06:00, reaches 64 ºC at 13:00 and then begins to fall.

The solar gains values start increasing at 07:00, reach their maximum amounts 21,81 kW at 11.00, and drop down to 0 at 17.00. The solar gains values are 0,052 kW; 0,868 kW; 4,86 kW; 13,81 kW; 21,81 kW; 18,35 kW; 16,75 kW; 9,98 kW; 7,57 kW and 4,36 kW respectively. The glazing losses values are minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00. The wall losses values are close to the each other and minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00.

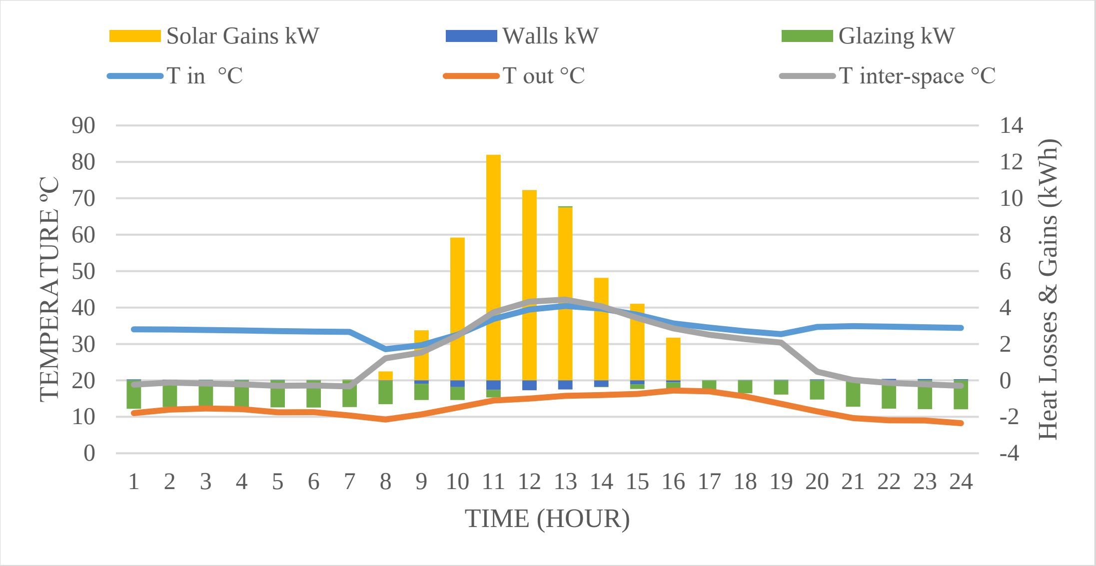


Figure 37 *on 18 January, Alternative 7 in Luxor*

As seen in (Figure 37), the indoor air, the outdoor air and the inter-space air temperatures are on January 18th, 34,62 ºC; 12,54 ºC and 26,89 ºC in respectively. The indoor air temperature drops down to 28,57 ºC at 08:00; after this time the temperature starts to increase up to 40,43 ºC at 13:00 and then begins to fall again to 32,71 ºC at 19:00. The outdoor air temperature drops down to 9,25 ºC at 08:00; starts to increase up to 17,22 ºC at 16:00 and then begins to fall to 8,25 ºC at 24:00. The inter-space air temperature starts to increase in 18,35 ºC at 07:00, reaches 42,17 ºC at 13:00 and then begins to fall.

The solar gains values start increasing at 07:00, reach their maximum amounts 21,81 kW at 11.00, and drop down to 0 at 17.00. The solar gains values are 0,052 kW; 0,868 kW; 4,86 kW; 13,81 kW; 21,81 kW; 18,35 kW; 16,75 kW; 9,98 kW; 7,57 kW and 4,36 kW respectively. The glazing losses values are close to the each other and minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00. The wall losses values are close to each other and minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00.

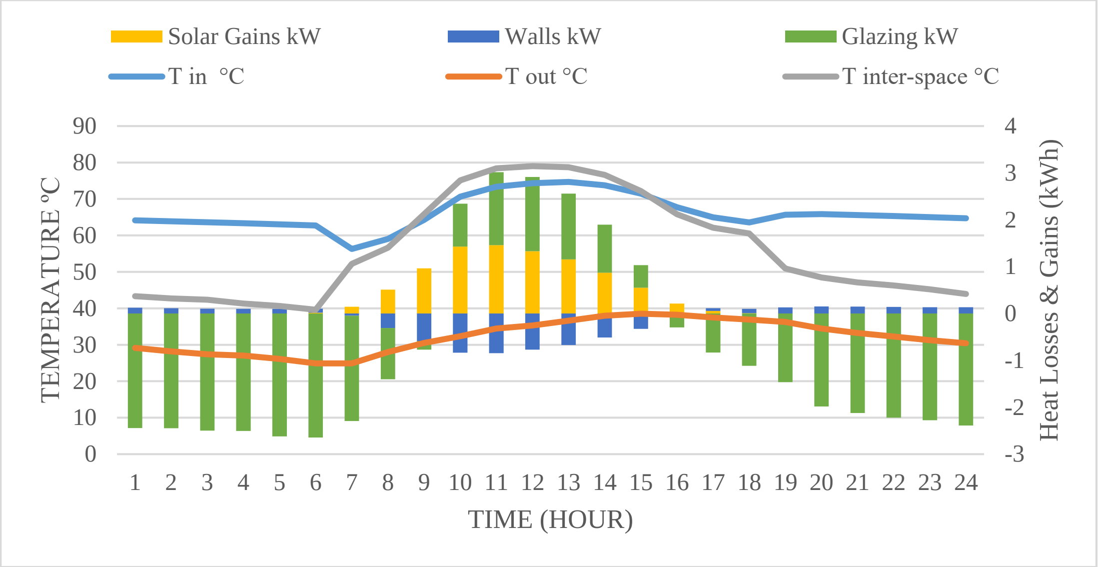


Figure 38 *on 18 July, Alternative 7 in Luxor*

As seen in (Figure 38), the indoor air, the outdoor air and the inter-space air temperatures are on July 18th, 66,12 ºC; 32,16 ºC and 56,46 ºC in respectively. The indoor air temperature drops down to 56,28 ºC at 07:00; after this time the temperature starts to increase up to 74,67 ºC at 13:00 and then begins to fall again to 63,56 ºC at 18:00. The outdoor air temperature drops down to 24,9 ºC at 06:00 - 07:00; starts to increase up to 38,52 ºC at 15:00 and then begins to fall to 30,4 ºC at 24:00. The inter-space air temperature starts to increase in 39,61 ºC at 06:00, reaches 79 ºC at 12:00 and then begins to fall.

The solar gains values start increasing at 07:00, reach their maximum amounts 21,81 kW at 11.00, and drop down to 0 at 17.00. The solar gains values are 0,052 kW; 0,868 kW; 4,86 kW; 13,81 kW; 21,81 kW; 18,35 kW; 16,75 kW; 9,98 kW; 7,57 kW and 4,36 kW respectively. The glazing losses values are minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00. The wall losses values are close to each other and minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00.

6.2. Simulation Results For Erzurum

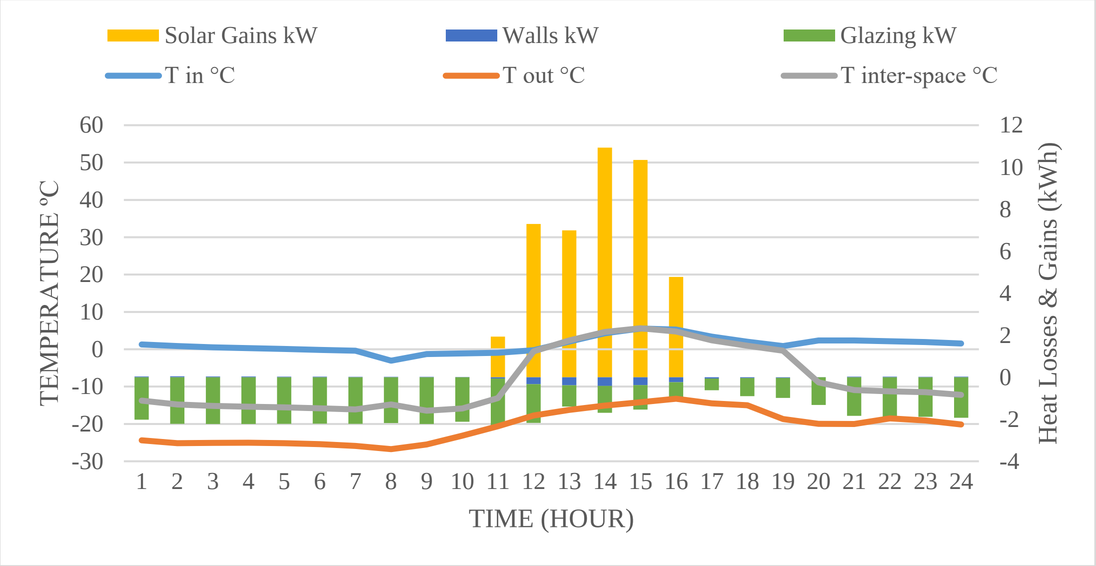


Figure 39 *on 18 January, Alternative 1 in Erzurum*

As seen in (Figure 39), the indoor air, the outdoor air and the inter-space air temperatures are on January 18th, 1,23 ºC; - 20,60 ºC and - 8,41 ºC in respectively. The indoor air temperature drops down to - 3,05 ºC at 08:00; after this time the temperature starts to increase up to 5,55 ºC at 15:00 and then begins to fall in - 0,38 ºC at 19:00. The outdoor air temperature drops down to - 26,75 ºC at 08:00 in respectively; starts to increase up to - 13,25 ºC at 16:00 and then begins to fall in - 20,15 ºC at 24:00. The inter-space air temperature starts to increase up to - 16,45 ºC at 09:00, reaches 5,62 ºC at 15:00 and then begins to fall.

The solar gains values start increasing at 07:00, reach their maximum amounts 21,81 kW at 11.00, and drop down to 0 at 17.00. The solar gains values are 0,052 kW; 0,868 kW; 4,86 kW; 13,81 kW; 21,81 kW; 18,35 kW; 16,75 kW; 9,98 kW; 7,57 kW and 4,36 kW respectively. The glazing lossess values are close to the each other and minimum -2,22 kW at 23:00; maximum -0,55 kW at 17:00. The wall lossess values are close to the each other and minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00.

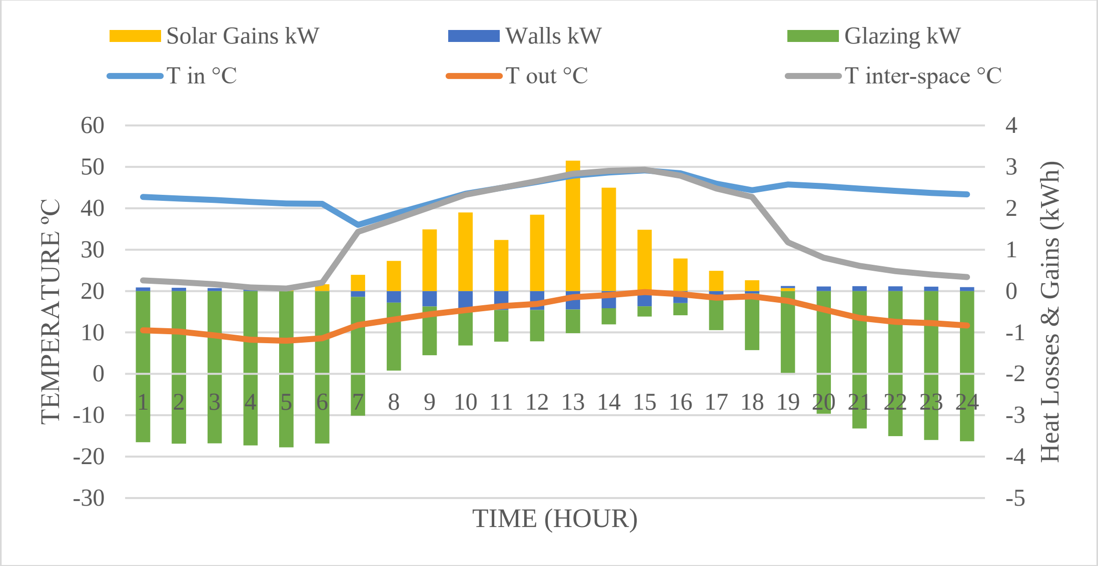


***Figure 40** on 18 July, Alternative 1 in Erzurum*

As seen in (Figure 40), the indoor air, the outdoor air and the inter-space air temperatures are on July 18th, 43,86 ºC; 14,15 ºC and 34,02 ºC in respectively. The indoor air temperature drops down to 35,98 ºC at 07:00; after this time the temperature starts to increase up to 49,13 ºC at 15:00 and then begins to fall in 44,36 ºC at 18:00. The outdoor air temperature drops down to 8 ºC at 05:00 in respectively; starts to increase up to 19,75 ºC at 15:00 and then begins to fall in 11,67 ºC at 24:00. The inter-space air temperature starts to increase up 20,60 ºC at 05:00, reaches 49,31 ºC at 15:00 and then begins to fall.

The solar gains values start increasing at 07:00, reach their maximum amounts 21,81 kW at 11.00, and drop down to 0 at 17.00. The solar gains values are 0,052 kW; 0,868 kW; 4,86 kW; 13,81 kW; 21,81 kW; 18,35 kW; 16,75 kW; 9,98 kW; 7,57 kW and 4,36 kW respectively. The glazing losses values are minimum -3,77 kW at 05:00; maximum -0,24 kW at 15:00. The wall losses values are close to each other and minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00.

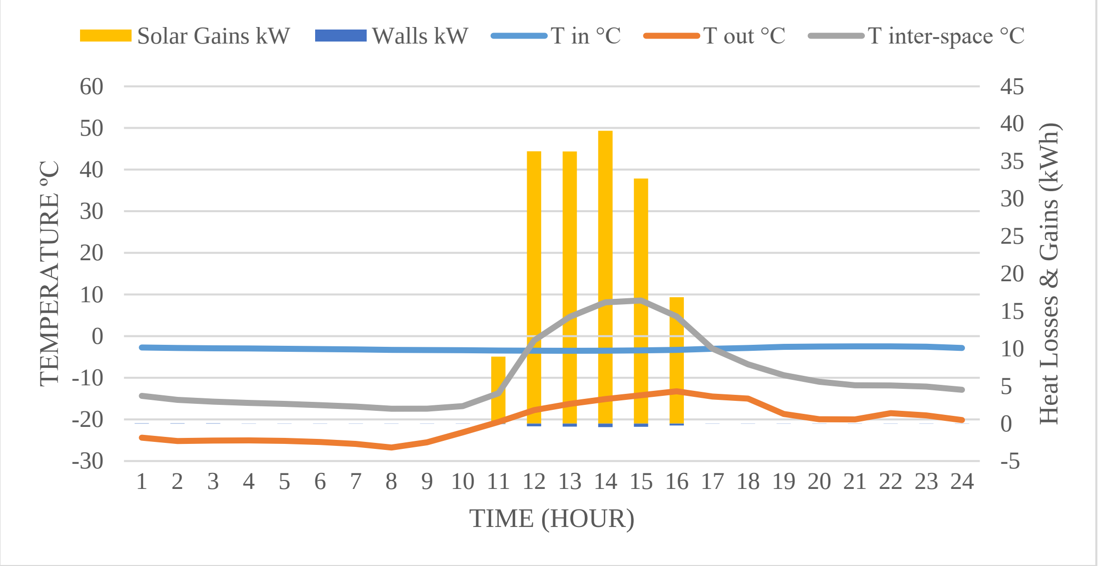


***Figure 41** on 18 January, Alternative 2 in Erzurum*

As seen in (Figure 41), the indoor air, the outdoor air and the inter-space air temperatures are on January 18th, - 3,03 ºC; - 20,60 ºC and - 9,59 ºC in respectively. The indoor air temperatures are close to each other and minimum - 3,51 ºC at 13:00; maximum - 2,45 ºC at 22:00. The outdoor air temperature drops down to - 26,75 ºC at 08:00 in respectively; starts to increase up to - 13,25 ºC at 16:00 and then begins to fall in - 20,15 ºC at 24:00. The inter-space air temperature starts to increase in - 16,81 ºC at 10:00, reaches 8,56 ºC at 15:00 and then begins to fall.

The solar gains values start increasing at 07:00, reach their maximum amounts 21,81 kW at 11.00, and drop down to 0 at 17.00. The solar gains values are 0,052 kW; 0,868 kW; 4,86 kW; 13,81 kW; 21,81 kW; 18,35 kW; 16,75 kW; 9,98 kW; 7,57 kW and 4,36 kW respectively. The glazing losses values are minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00. The wall losses values are close to the each other and minimum - 3,36 kW at 23:00; maximum -1,35 kW at 14:00.

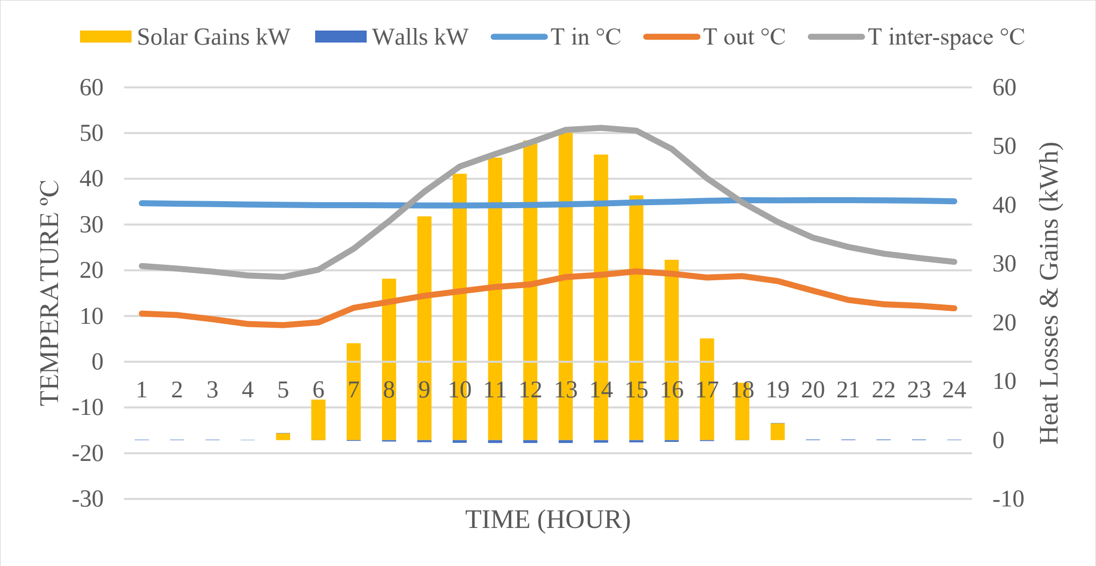


Figure 42 *on 18 July, Alternative 2 in Erzurum*

As seen in (Figure 42), the indoor air, the outdoor air and the inter-space air temperatures are on July 18th, 34,69 ºC; 14,15 ºC and 32,16 ºC in respectively. The indoor air temperatures are close to each other and a minimum of 34,16 ºC at 10:00; a maximum of 35,33 ºC at 21:00. The outdoor air temperature drops down to 8 ºC at 05:00 in respectively; starts to increase up to 19,75 ºC at 15:00 and then begins to fall in 11,67 ºC at 24:00. The inter-space air temperature starts to increase in 18,54 ºC at 05:00, reaches 51,13 ºC at 14:00 and then begins to fall.

The solar gains values start increasing at 07:00, reach to their maximum amounts 21,81 kW at 11.00, and drop down to 0 at 17.00. The solar gains values are 0,052 kW; 0,868 kW; 4,86 kW; 13,81 kW; 21,81 kW; 18,35 kW; 16,75 kW; 9,98 kW; 7,57 kW and 4,36 kW respectively. The glazing lossess values are minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00. The wall lossess values are close to the each other and minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00.

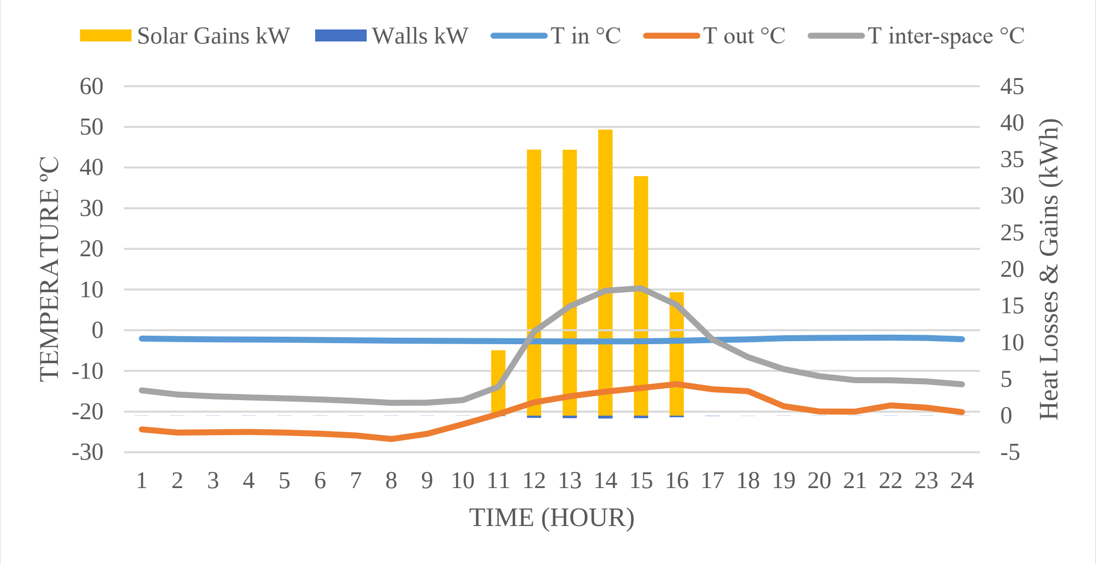


Figure 43 *on 18 January, Alternative 3 in Erzurum*

As seen in (Figure 43), the indoor air, the outdoor air and the inter-space air temperatures are on January 18th, - 2,34 ºC; - 20,60 ºC and - 9,57 ºC in respectively. The indoor air temperatures are close to each other and minimum - 2,75 ºC at 14:00; maximum - 1,82 ºC at 22:00. The outdoor air temperature drops down to - 26,75 ºC at 08:00 in respectively; starts to increase up to - 13,25 ºC at 16:00 and then begins to fall in - 20,15 ºC at 24:00. The inter-space air temperature starts to increase in - 17,81 ºC at 09:00, reaches to 10,30 ºC at 15:00 and then begins to fall.

The solar gains values start increasing at 07:00, reach to their maximum amounts 21,81 kW at 11.00, and drop down to 0 at 17.00. The solar gains values are 0,052 kW; 0,868 kW; 4,86 kW; 13,81 kW; 21,81 kW; 18,35 kW; 16,75 kW; 9,98 kW; 7,57 kW and 4,36 kW respectively. The glazing lossess values are minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00. The wall lossess values are close to the each other and minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00.

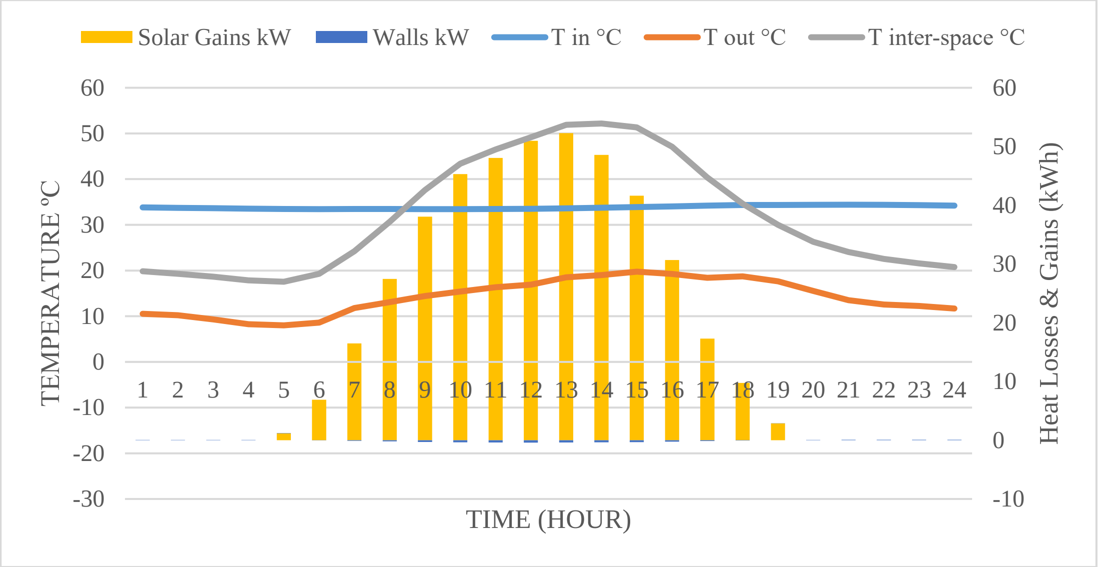


Figure 44 *on 18 July, Alternative 3 in Erzurum*

As seen in (Figure 44), the indoor air, the outdoor air and the inter-space air temperatures are on July 18th, 33,84 ºC; 14,15 ºC and 31,94 ºC in respectively. The indoor air temperatures are close to each other and a minimum of 33,43 ºC at 06:00; a maximum of 34,40 ºC at 21:00. The outdoor air temperature drops down to 8 ºC at 05:00 in respectively; starts to increase up to 19,75 ºC at 15:00 and then begins to fall in 11,67 ºC at 24:00. The inter-space air temperature starts to increase in 17,54 ºC at 05:00, reaches 52,17 ºC at 14:00 and then begins to fall.

The solar gains values start increasing at 07:00, reach to their maximum amounts 21,81 kW at 11.00, and drop down to 0 at 17.00. The solar gains values are 0,052 kW; 0,868 kW; 4,86 kW; 13,81 kW; 21,81 kW; 18,35 kW; 16,75 kW; 9,98 kW; 7,57 kW and 4,36 kW respectively. The glazing lossess values are minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00. The wall lossess values are close to the each other and minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00.

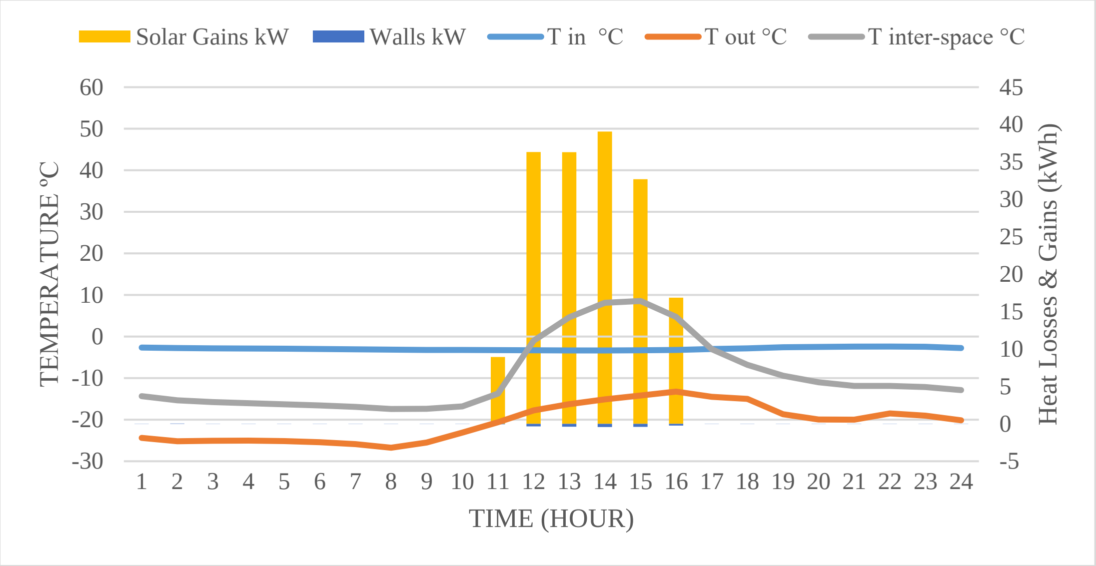


Figure 45 *on 18 January, Alternative 4 in Erzurum*

As seen in (Figure 45), the indoor air, the outdoor air and the inter-space air temperatures are on January 18th, - 2,93 ºC; - 20,60 ºC and - 9,61 ºC in respectively. The indoor air temperatures are close to each other and minimum - 3,35 ºC at 14:00; maximum - 2,40 ºC at 22:00. The outdoor air temperature drops down to - 26,75 ºC at 08:00 in respectively; starts to increase up to - 13,25 ºC at 16:00 and then begins to fall in - 20,15 ºC at 24:00. The inter-space air temperature starts to increase in - 17,42 ºC at 08:00, reaches 8,55 ºC at 15:00 and then begins to fall.

The solar gains values start increasing at 07:00, reach to their maximum amounts 21,81 kW at 11.00, and drop down to 0 at 17.00. The solar gains values are 0,052 kW; 0,868 kW; 4,86 kW; 13,81 kW; 21,81 kW; 18,35 kW; 16,75 kW; 9,98 kW; 7,57 kW and 4,36 kW respectively. The glazing lossess values are minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00. The wall lossess values are close to the each other and minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00.

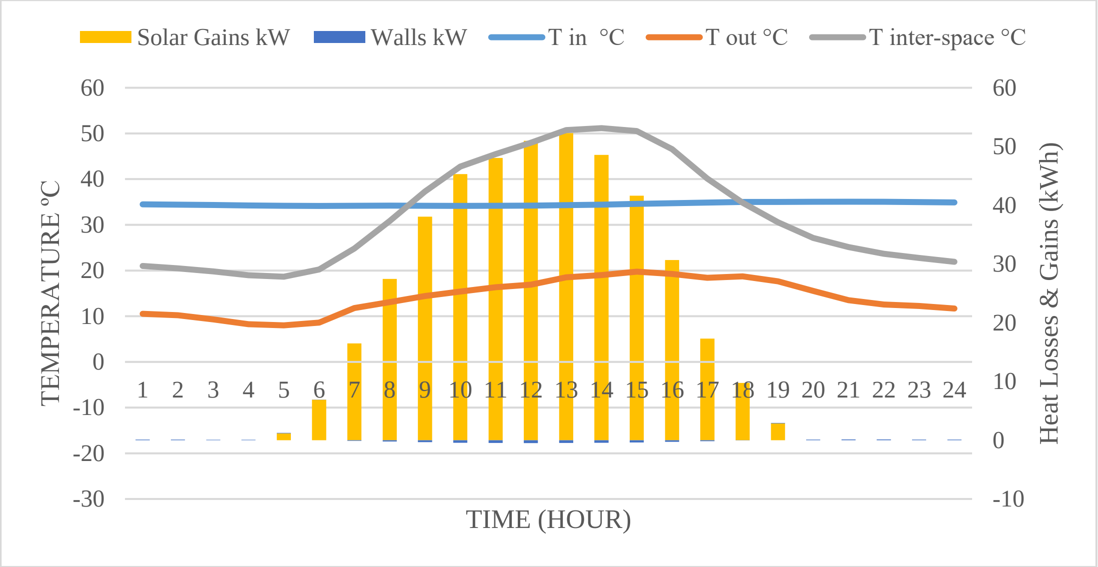


Figure 46 *on 18 July, Alternative 4 in Erzurum*

As seen in (Figure 46), the indoor air, the outdoor air and the inter-space air temperatures are on July 18th, 34,53 ºC; 14,15 ºC and 32,21 ºC in respectively. The indoor air temperatures are close to each other and a minimum of 34,14 ºC at 06:00 and 10:00; a maximum of 35,05 ºC at 21:00. The outdoor air temperature drops down to 8 ºC at 05:00 in respectively; starts to increase up to 19,75 ºC at 15:00 and then begins to fall in 11,67 ºC at 24:00. The inter-space air temperature starts to increase in 18,64 ºC at 05:00, reaches 51,15 ºC at 14:00 and then begins to fall.

The solar gains values start increasing at 07:00, reach to their maximum amounts 21,81 kW at 11.00, and drop down to 0 at 17.00. The solar gains values are 0,052 kW; 0,868 kW; 4,86 kW; 13,81 kW; 21,81 kW; 18,35 kW; 16,75 kW; 9,98 kW; 7,57 kW and 4,36 kW respectively. The glazing lossess values are minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00. The wall lossess values are close to the each other and minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00.

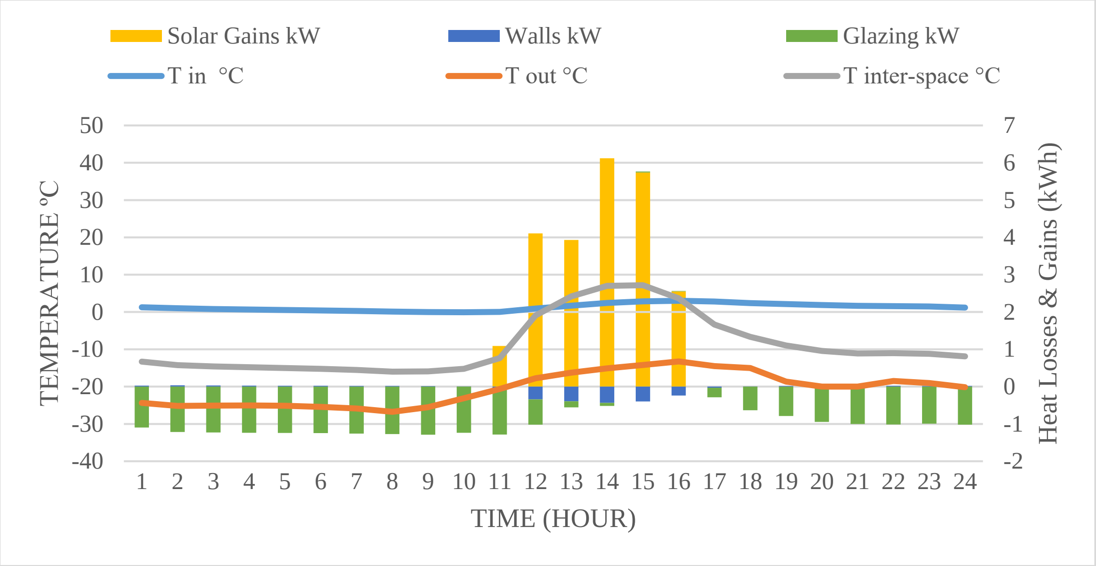


Figure 47 *on 18 January, Alternative 5 in Erzurum*

As seen in (Figure 47), the indoor air, the outdoor air and the inter-space air temperatures are on January 18th, 1,29 ºC; - 20,60 ºC and - 9 ºC in respectively. The indoor air temperature drops down to 0 ºC at 11:00; after this time the temperature starts to increase up to 3 ºC at 16:00 and then begins to fall again. The outdoor air temperature drops down to - 26,75 ºC at 08:00 in respectively; starts to increase up to - 13,25 ºC at 16:00 and then begins to fall in - 20,15 ºC at 24:00. The inter-space air temperature starts to increase up to 7 ºC at 15:00 and then begins to fall again.

The solar gains values start increasing at 07:00, reach their maximum amounts 21,81 kW at 11.00, and drop down to 0 at 17.00. The solar gains values are 0,052 kW; 0,868 kW; 4,86 kW; 13,81 kW; 21,81 kW; 18,35 kW; 16,75 kW; 9,98 kW; 7,57 kW and 4,36 kW respectively. The glazing losses values are close to each other and minimum -1,28 kW at 09:00; maximum 0,02 kW at 15:00. The wall losses values are close to each other and minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00.

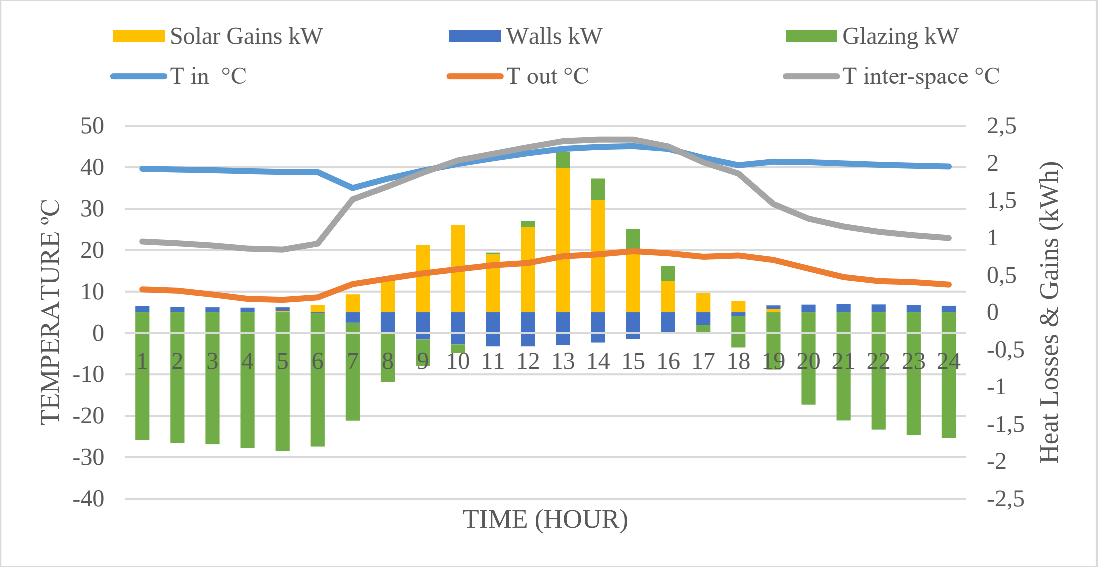


Figure 48 *on 18 July, Alternative 5 in Erzurum*

As seen in (Figure 48), the indoor air, the outdoor air and the inter-space air temperatures are on July 18th, 40,79 ºC; 14,15 ºC and 32,60 ºC in respectively. The indoor air temperature drops down to 34,98 ºC at 07:00; after this time the temperature starts to increase up to 45,09 ºC at 15:00 and then begins to fall in 40,19 ºC at 24:00. The outdoor air temperature drops down to 8 ºC at 05:00 in respectively; starts to increase up to 19,75 ºC at 15:00 and then begins to fall in 11,67 ºC at 24:00. The inter-space air temperature starts to increase in 20,12 ºC at 05:00, reaches 46,68 ºC at 14:00 and then begins to fall.

The solar gains values start increasing at 07:00, reach to their maximum amounts 21,81 kW at 11.00, and drop down to 0 at 17.00. The solar gains values are 0,052 kW; 0,868 kW; 4,86 kW; 13,81 kW; 21,81 kW; 18,35 kW; 16,75 kW; 9,98 kW; 7,57 kW and 4,36 kW respectively. The glazing lossess values are minimum -3,36 kW at 06:00; maximum 0,30 kW at 15:00. The wall lossess values are close to the each other and minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00.

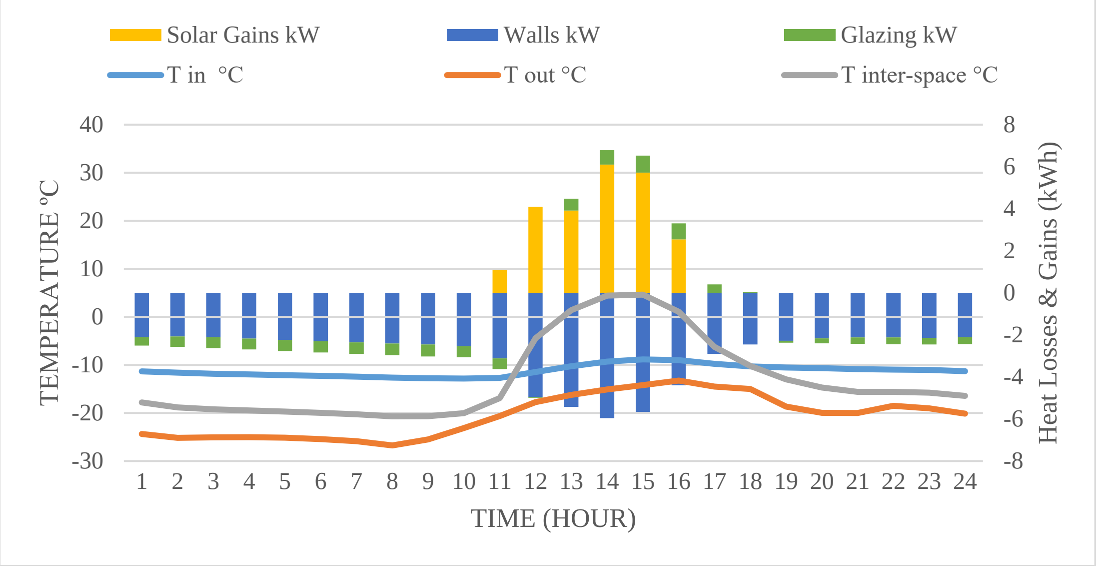


***Figure 49** on 18 January, Alternative 6 in Erzurum*

As seen in (Figure 49), the indoor air, the outdoor air and the inter-space air temperatures are on January 18th, - 11,20 ºC; - 20,60 ºC and - 13,08 ºC in respectively. The indoor air temperature drops down to - 12,83 ºC at 10:00; after this time the temperature starts to increase up to - 8,84 ºC at 15:00 and then begins to fall again. The outdoor air temperature drops down to - 26,75 ºC at 08:00 in respectively; starts to increase up to - 13,25 ºC at 16:00 and then begins to fall in - 20,15 ºC at 24:00. The inter-space air temperature starts to increase in - 20,69 ºC at 08:00, reaches 4,63 ºC at 15:00 and then begins to fall.

The solar gains values start increasing at 07:00, reach their maximum amounts 21,81 kW at 11.00, and drop down to 0 at 17.00. The solar gains values are 0,052 kW; 0,868 kW; 4,86 kW; 13,81 kW; 21,81 kW; 18,35 kW; 16,75 kW; 9,98 kW; 7,57 kW and 4,36 kW respectively. The glazing losses values are close to each other and minimum -3,36 kW at 23:00; maximum 0,81 kW at 15:00. The wall losses values are close to each other and minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00.

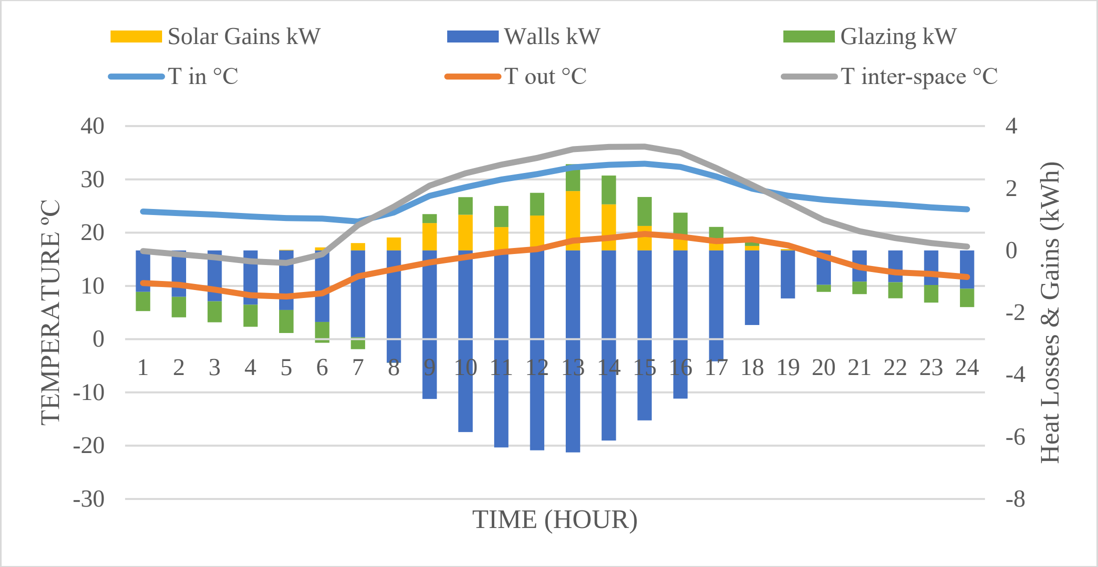


Figure 50 *on 18 July, Alternative 6 in Erzurum*

As seen in (Figure 50), the indoor air, the outdoor air and the inter-space air temperatures are on July 18th, 26,82 ºC; 14,15 ºC and 24,68 ºC in respectively. The indoor air temperature drops down to 22,08 ºC at 07:00; after this time the temperature starts to increase up to 32,93 ºC at 15:00 and then begins to fall in 24,37 ºC at 24:00. The outdoor air temperature drops down to 8 ºC at 05:00 in respectively; starts to increase up to 19,75 ºC at 15:00 and then begins to fall in 11,67 ºC at 24:00. The inter-space air temperature starts to increase in 14,30 ºC at 05:00, reaches 36,13 ºC at 15:00 and then begins to fall in 17,37 ºC at 24:00.

The solar gains values start increasing at 07:00, reach to their maximum amounts 21,81 kW at 11.00, and drop down to 0 at 17.00. The solar gains values are 0,052 kW; 0,868 kW; 4,86 kW; 13,81 kW; 21,81 kW; 18,35 kW; 16,75 kW; 9,98 kW; 7,57 kW and 4,36 kW respectively. The glazing lossess values are minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00. The wall lossess values are close to the each other and minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00.

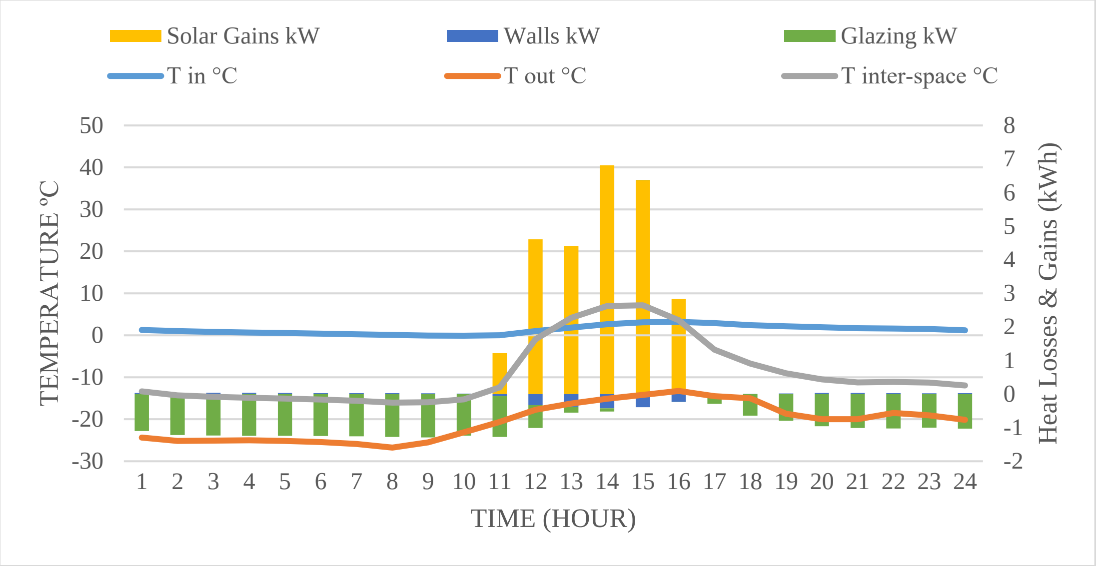


***Figure 51** on 18 January, Alternative 7 in Erzurum*

As seen in (Figure 51), the indoor air, the outdoor air and the inter-space air temperatures are on January 18th, 1,34 ºC; - 20,60 ºC and - 9,04 ºC in respectively. The indoor air temperatures drop down to - 0,09 ºC at 08:00; after this time the temperature starts to increase up to 3,20 ºC at 16:00 and then begins to fall again. The outdoor air temperature drops down to - 26,75 ºC at 08:00 in respectively; starts to increase up to - 13,25 ºC at 16:00 and then begins to fall in - 20,15 ºC at 24:00. The inter-space air temperature starts to increase in - 16,04 ºC at 08:00, reaches to 7,15 ºC at 15:00 and then begins to fall.

The solar gains values start increasing at 07:00, reach their maximum amounts 21,81 kW at 11.00, and drop down to 0 at 17.00. The solar gains values are 0,052 kW; 0,868 kW; 4,86 kW; 13,81 kW; 21,81 kW; 18,35 kW; 16,75 kW; 9,98 kW; 7,57 kW and 4,36 kW respectively. The glazing losses values are close to each other and minimum -3,36 kW at 23:00; maximum 0,01 kW at 15:00. The wall losses values are close to each other and minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00.

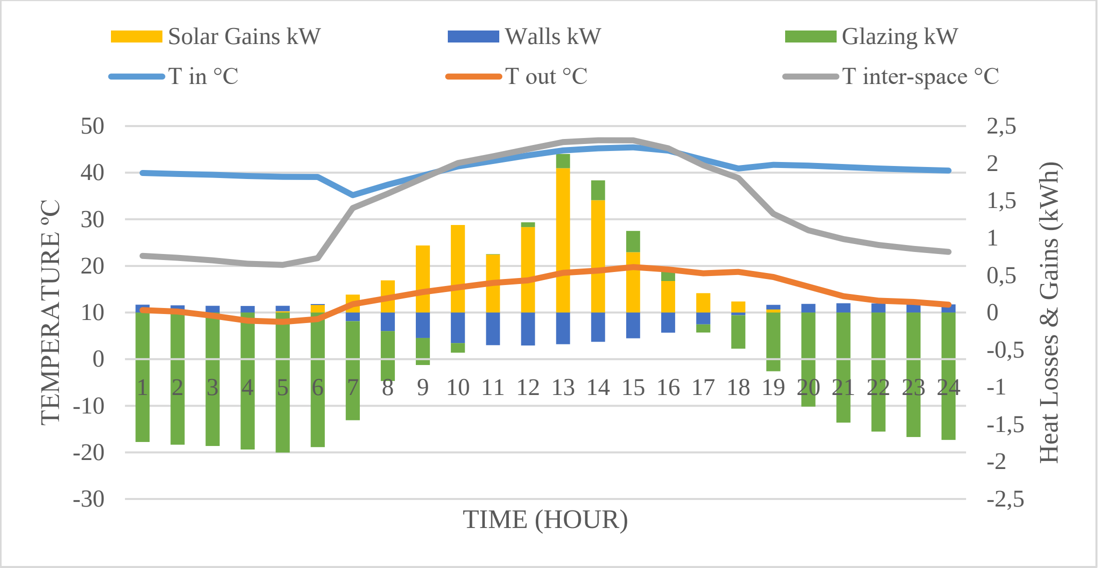


***Figure 52** on 18 July, Alternative 7 in Erzurum*

As seen in (Figure 52), the indoor air, the outdoor air and the inter-space air temperatures are on July 18th, 41,10 ºC; 14,15 ºC and 32,77 ºC in respectively. The indoor air temperature drops down to 35,17 ºC at 07:00; after this time the temperature starts to increase up to 45,43 ºC at 15:00 and then begins to fall in 40,45 ºC at 24:00. The outdoor air temperature drops down to 8 ºC at 05:00 in respectively; starts to increase up to 19,75 ºC at 15:00 and then begins to fall in 11,67 ºC at 24:00. The inter-space air temperature starts to increase in 20,21 ºC at 05:00, reaches 46,95 ºC at 14:00 and then begins to fall in 22,99 ºC at 24:00.

The solar gains values start increasing at 07:00, reach their maximum amounts 21,81 kW at 11.00, and drop down to 0 at 17.00. The solar gains values are 0,052 kW; 0,868 kW; 4,86 kW; 13,81 kW; 21,81 kW; 18,35 kW; 16,75 kW; 9,98 kW; 7,57 kW and 4,36 kW respectively. The glazing losses values are close to each other and minimum -3,36 kW at 23:00; maximum 0,28 kW at 15:00. The wall losses values are close to each other and minimum -3,36 kW at 23:00; maximum -1,35 kW at 14:00.

6.3. Discussion

The air temperatures have been given in the following order: the indoor air, the outdoor air and the inter-space air temperatures respectively.

__Figure 53__ Results for fully window wall and concrete wall in Luxor

As seen in (Figure 53), when practiced as Alternative 1 (fully window wall), the month January has reached to 37ºC; 12,5ºC and 28ºC, while 68ºC; 32ºC and 57ºC have been achieved in month July. When used as Alternative 2 (concrete wall), the month January has reached to 29,5ºC; 12,5ºC and 25,6ºC while 57,65ºC; 32,16ºC and 56ºC have been achieved in the month July. If the wall is compared to the condition of fully window and concrete, it is achieved that the usage of concrete walls for the indoor temperature is better.

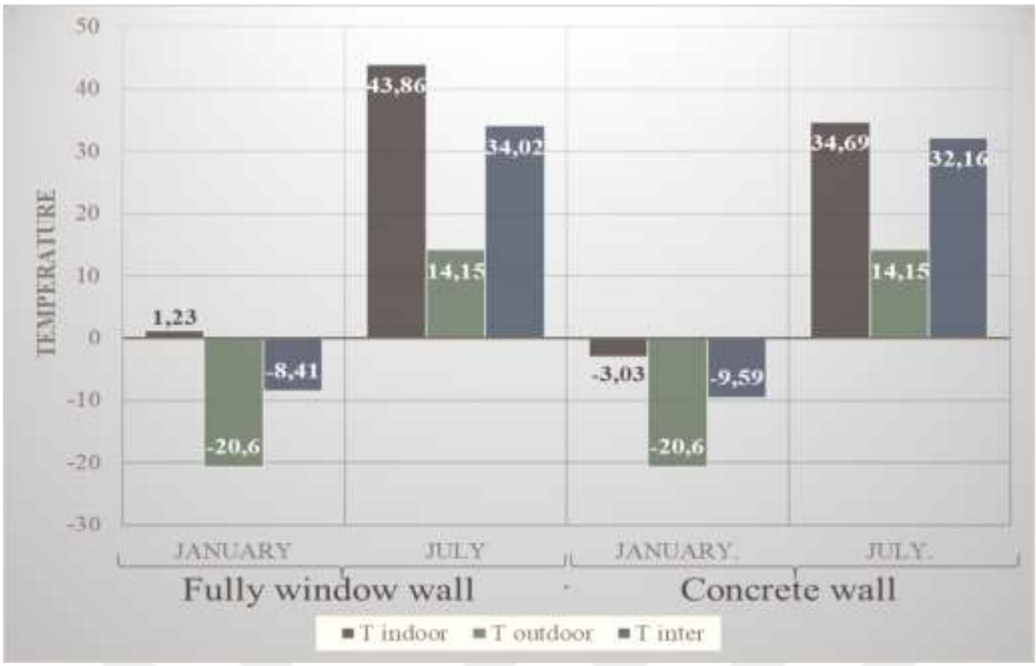


Figure 54 *Results for fully window wall and concrete wall in Erzurum*

As seen in (Figure 54), when practiced as Alternative 1 (fully window wall), the month January has reached to 1,23ºC; - 20,60ºC and - 8,41ºC, while 43,86ºC; 14,15ºC and 34,02ºC have been achieved in the month July. When used as Alternative 2 (concrete wall), the month January has reached to - 3,03ºC; - 20,60ºC and - 9,59ºC while 34,69ºC; 14,15ºC and 32,16ºC have been achieved in the month July. If the wall is compared to the condition of fully window and concrete, it is achieved that the usage of concrete walls for the indoor temperature is better.

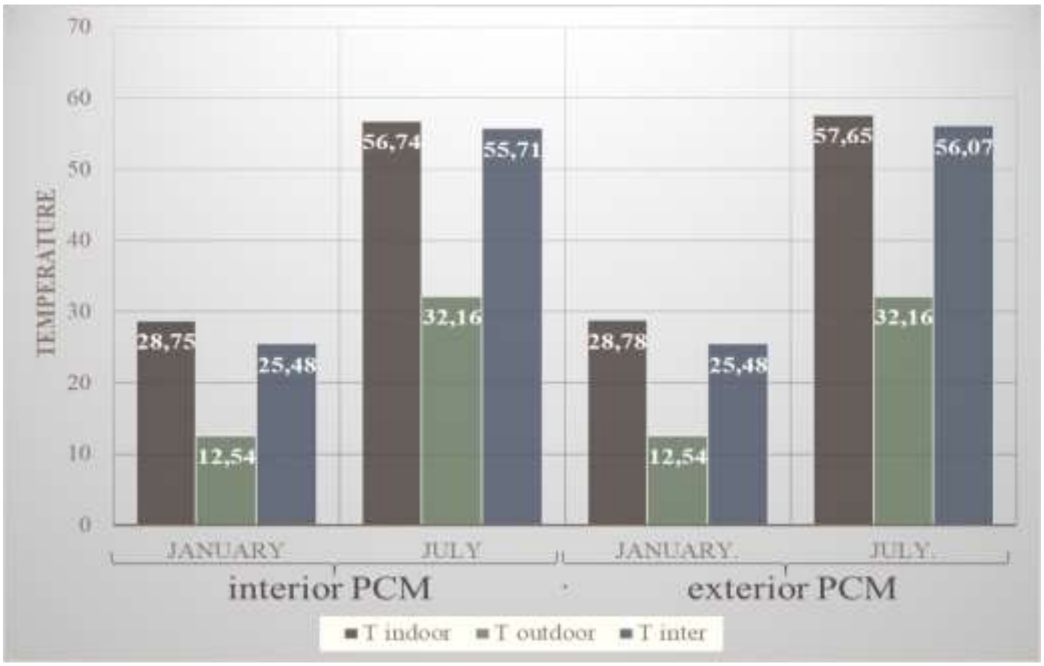


***Figure 55** Results for interior PCM and exterior PCM in Luxor*

As seen in (Figure 55), when practiced as Alternative 3 (concrete wall and PCM in the interior part of this wall), the month January has reached to 28,75ºC; 12,54ºC and 25,48ºC while 56,74ºC, 32,16ºC and 55,71ºC has been achieved in the month July. When used as Alternative 4 (concrete wall and PCM in the exterior part of this wall), the month January has reached to 28,78ºC, 12,54ºC and 25,48ºC while 57,65ºC, 32,16ºC and 56,07ºC have been achieved in the month July.

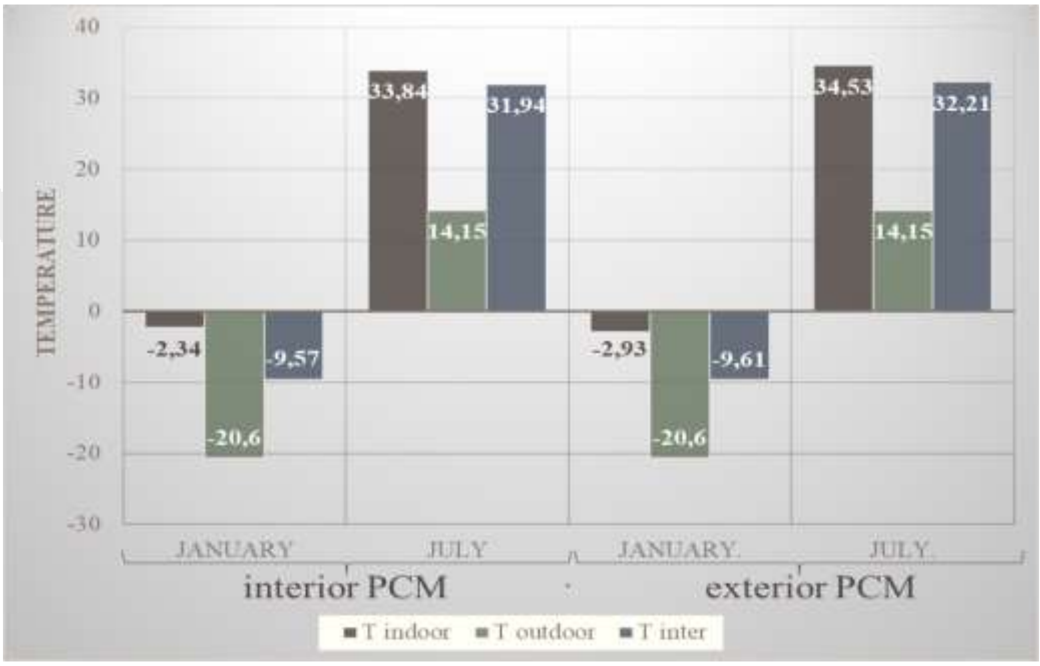


***Figure 56** Results for interior PCM and exterior PCM in Erzurum*

As seen in (Figure 56), when practiced as Alternative 3 (concrete wall and PCM in the interior part of this wall), the month January has reached to - 2,34ºC; - 20,60 ºC and - 9,57ºC while 33,84ºC; 14,15ºC and 31,94ºC have been achieved in the month July. When used as Alternative 4 (concrete wall and PCM in the exterior part of this wall), the month January has reached to - 2,93ºC; - 20,60ºC and - 9,61ºC while 34,53ºC; 14,15ºC and 32,21ºC have been achieved in the month July.

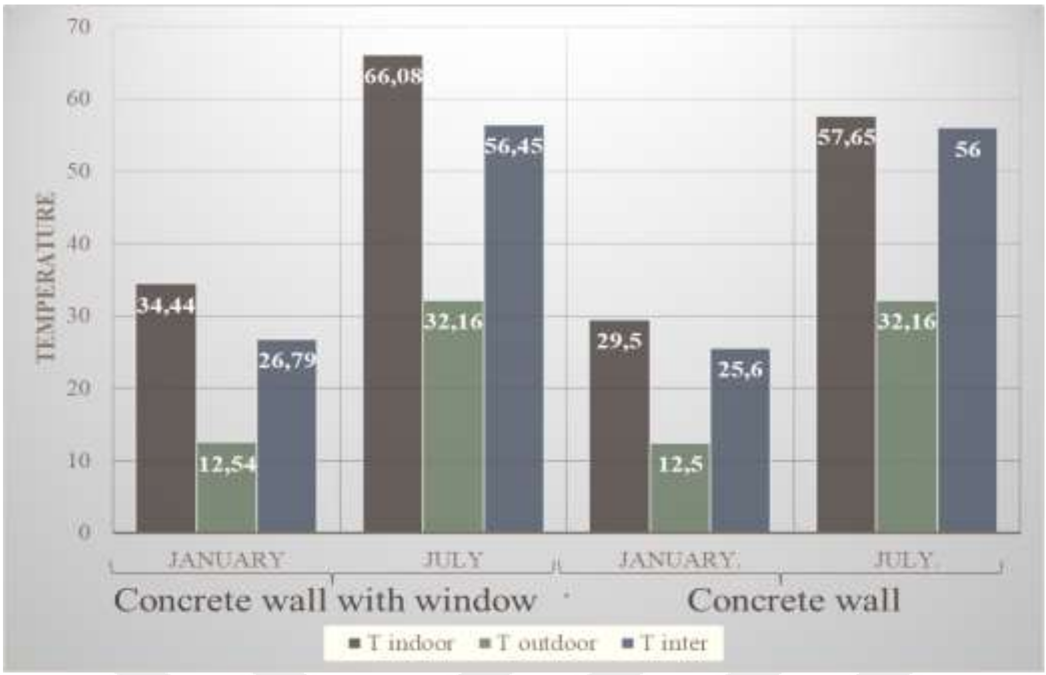


__Figure 57__ Results for concrete wall with window and concrete wall in Luxor

As seen in (Figure 57), when practiced as Alternative 5 (a concrete wall with window), the month January has reached to 34,44ºC, 12,54ºC and 26,79ºC, while 66,08ºC, 32,16ºC and 56,45ºC have been achieved in the month July. The situation in which the window is closed will be chosen. When compared to the case, the window is located on the wall and is not, the temperature values have increased for both of the months in Alternative 5.

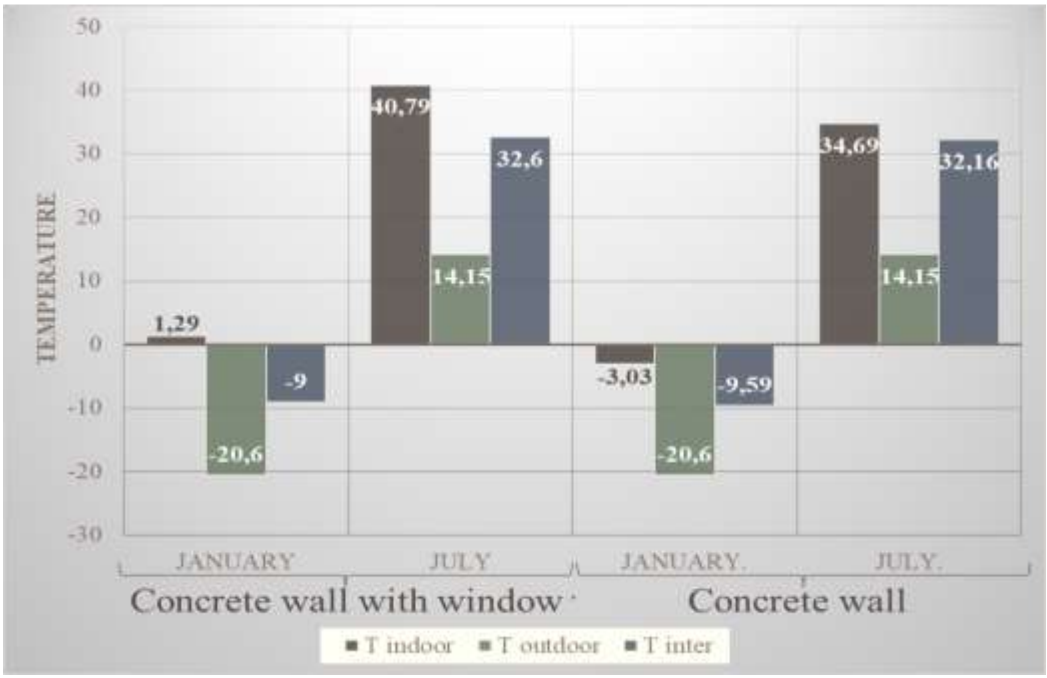


Figure 58 *Results for concrete wall with window and concrete wall in Erzurum*

As seen in (Figure 58), when practiced as Alternative 5 (a concrete wall with window), the month January has reached to 1,29ºC; - 20,60ºC and - 9ºC, while 40,79 ºC; 14,15ºC and 32,60ºC have been achieved in the month July. The situation in which the window is closed will be chosen. When compared to the case, the window is located on the wall and is not, the temperature values have increased for both of months in Alternative 5. The condition of with window for January and without window for July has been found good.

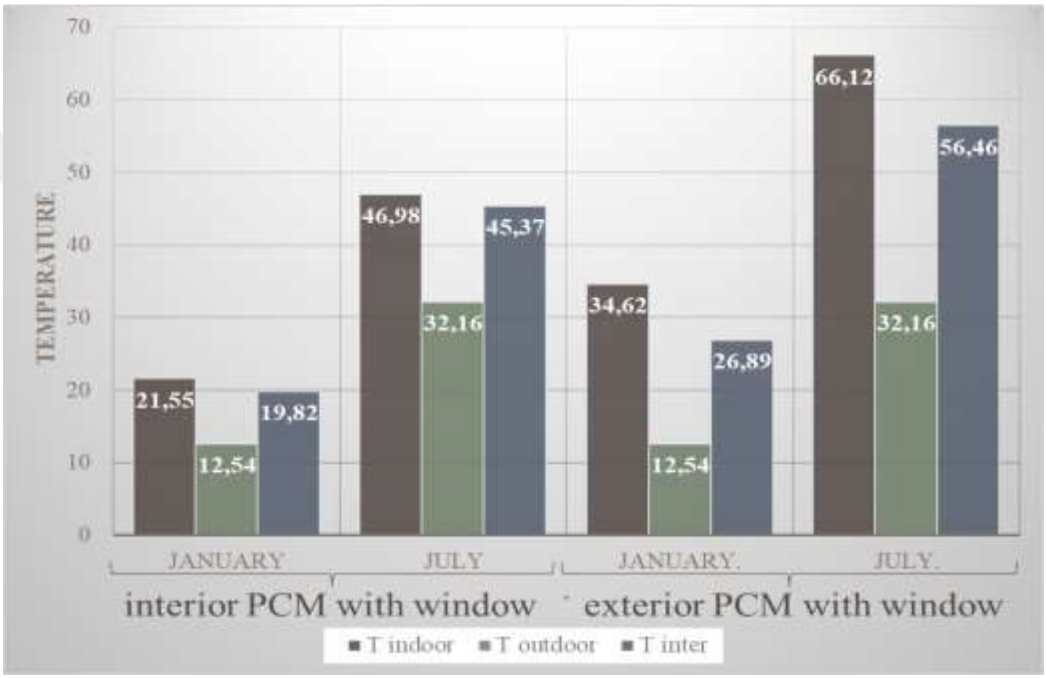


Figure 59 *Results for window with interior PCM and exterior PCM in Luxor*

As seen in (Figure 59), when practiced as Alternative 6 (a concrete wall with window and PCM in the interior part of this wall, the month January has reached to 21,55ºC; 12,54ºC and 19,82ºC, while 46,98ºC; 32,16ºC and 45,37ºC have been achieved in the month July. When used as Alternative 7 (concrete wall with window and PCM in the exterior part of this wall), the month January has reached to 34,62ºC; 12,54ºC and 26,89ºC, while 66,12ºC; 32,16ºC and 56,46ºC have been achieved in the month July. If the position of the PCM material is compared, it is found that the use of PCM for January is better for the indoor air temperature than the situation in which it is used (because it is close to the indoor ambient temperature). For July, this situation is the opposite, where it is used inside, which is more suitable for interior thermal comfort.

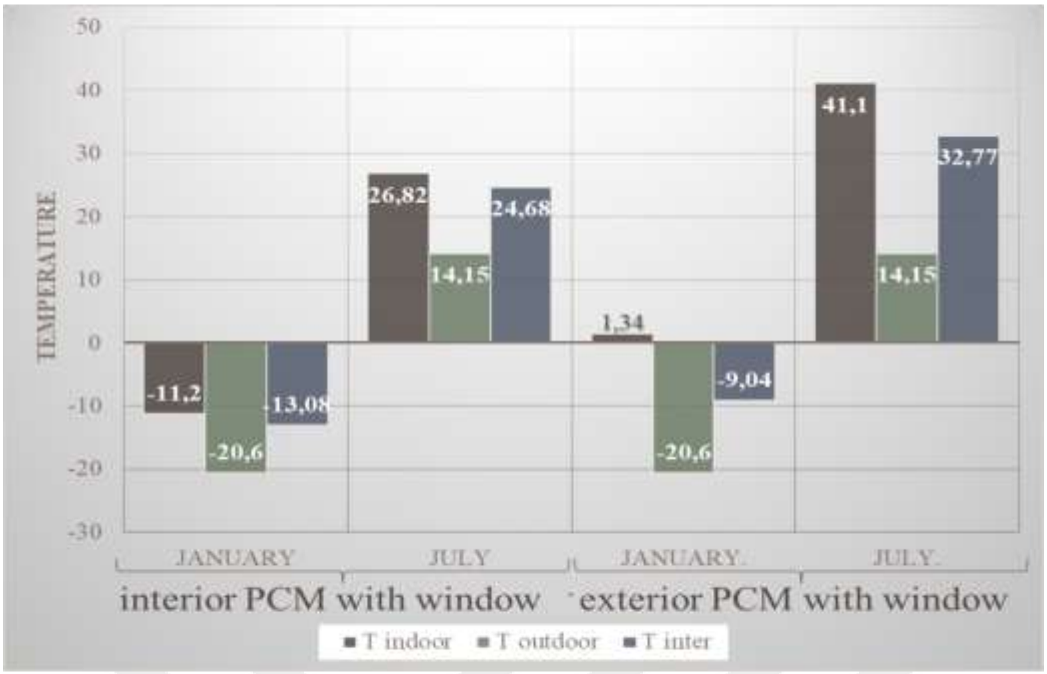


Figure 60 *Results for window with interior PCM and exterior PCM in Erzurum*

As seen in (Figure 60), when practiced as Alternative 6 (a concrete wall with window and PCM in the interior part of this wall), the month January has reached to -11,20 ºC; - 20,60ºC and - 13,08ºC; while 26,82 ºC; 14,15 ºC and 24,68 ºC have been achieved in the month July. When used as Alternative 7 (concrete wall with window and PCM in the exterior part of this wall), the month January has reached to 1,34ºC; -20,60ºC and -9,04ºC, while 41,10ºC; 14,15ºC and 32,77ºC have been achieved in the month July. If the position of the PCM material is compared, it is found that the use of PCM for January is better for the indoor temperature than the situation in which it is used (because it is close to the indoor ambient temperature). For July, this situation is the opposite, where it is used inside, which is more suitable for interior comfort.

CHAPTER 7

CONCLUSIONS AND FUTURE RESEARCH

Global climate change is highly related to the lifestyle of habitant’s because it has a negative impression on life. The climate’s impact on the energy consumption of the built environment is an undoubted fact that is crucially effective on the habitant’ lifestyle in the cities while changing their habits on the consuming energy (Retrieved 18 March 2019, from https://www.ipcc.ch/sr15/). Not only does the global climate change affect the lives of living creatures, but also, it affects the environment they live in. Nowadays, an exerting effort has been made all over the world to mitigate the climate change. Therefore, figuring out various methods to optimize the EUI for the built environment is an asset.

There will be an increase in urban construction sites and energy-consuming devices such as air conditioning, which will further increase energy consumption due to an improvement in living standards and rapid urbanization. For a concrete sample, the office personals are utilizing the artificial lighting in the daytime or cooling-heating without any thermal stress in their work environment to cause redundant consumption in the building scale. If highlighted in the wider frame, all these human behaviors for the unnecessary utility of energy cause the climate changes implicitly on a global scale. At this point, under changing conditions, the building's construction material is at a crucial point. In order to combat these changes in the external environment, the use of materials such as PCM, which operates with thermal energy storage, should become widespread. This research evaluates the performance of PCM material used on the integrated wall of the greenhouse structure integrated into the southern facade of a room model. The position on the wall where PCM material is used that may occur on this wall (such as the use of windows) is evaluated.

In this study, it was analyzed for 2 climate types in the DesignBuilder program through the effect of PCM; hot-dry and cold-humid. Luxor for the hot and dry climate zone and Erzurum for the cold and humid climate zone have been selected. DesignBuilder uses the EnergyPlus weather data. There are 7 different alternatives consisting of the same materials' layers for each region. Air temperatures are obtained in situations where the HVAC system is not working. Simulations have been made for July 18, which is considered to be the day when cooling is considered to be the most requested for the summer period, and January 18, which is considered to be the day when heating is considered the most requested for the winter period. Because the climate conditions of the selected regions are different, the assessments are made in itself.

As a result;

- Alternative 6 which represents interior PCM application with window is the most suitable for both climate types in the summertime period.
- Besides summertime suitability, Alternative 6 is an efficient choice to use for Luxor in the wintertime period.
- However, simulation results for Erzurum demonstrate that Alternative 7 which is exterior PCM application with window has a better deal for wintertime period while the further consideration is needed by the sense of material details.

As a result of the study, individual evaluation of locations has been made, and the results are the same for each other. The results can assist architects with the location selection and the usage of PCM material. This indicates that there is a set of solutions to the designer with the tool used in this study.

For future research, other systems such as BioPCM can be analyzed via computer software. By optimizing these data, it is possible to get more results and compare faster and reach more suitable variations. The effect of night-time ventilation (cooling) has not been taken into consideration because the windows have been treated closed while the simulations have been carried out. The results show that the night-time ventilation is an integral part of this system and thus, a future study might be done considering night-time ventilation for reaching better performances in hot climatic regions in cooling periods. In addition to these variables, structural elements might also be discussed such as building floor heights and etc.

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