AN INVESTIGATION OF TRANSIENT THERMAL BEHAVIORS OF BUILDING EXTERNAL WALLS

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ABSTRACT

AN INVESTIGATION OF TRANSIENT THERMAL BEHAVIOURS OF BUILDING EXTERNAL WALLS

Heat transfer problem of the building opaque wall surfaces are highly important for providing thermal comfort for different climatic conditions and orientations. In this study, the insulation models with external, internal and center positioned insulation materials are parametrically analyzed regarding their time dependent thermal behaviors. One-dimensional time-dependent heat conduction equation is investigated by solving via implicit finite difference method for summer and winter climatic conditions; and north, south, east and west orientations. Meteorological data for Ankara, Erzurum, İstanbul and İzmir, which are cities with different climatic conditions, are used in these calculations. The results indicate that, sandwich wall insulated type gives more convenient results regarding the heating loads for winter and cooling loads for summer, for each investigated city and directions.

ÖZET

BİNA DIŞ DUVARLARININ ZAMANA BAĞLI ISIL DAVRANIŞLARININ İNCELENMESİ

Binaların opak duvar yüzeylerindeki ısı transferi problemi, yıl boyunca değişik iklim koşulları ve yönlenmelere bağlı olarak, sağlanmak istenen ısıl konfor şartlarının elde edilmesi bağlamında oldukça önemlidir. Bu çalışmada, opak duvar yüzeylerinde kullanılan yalıtım malzemesinin dışta, ortada ve içte konumlandırıldığı yalıtım modelleri, zamana bağlı ısıl davranışları açısından parametrik olarak analiz edilmiştir. Yaz ve kış mevsim koşulları ile kuzey, güney, doğu ve batı yönlenme durumlarında, bir boyutlu zamana bağlı ısı iletim denklemi, sonlu farklar yöntemi kullanılarak, ısı kazanç ve kayıpları açısından irdelenmiştir. Bu analizler, farklı iklim koşullarına sahip olan Ankara, Erzurum, İstanbul ve İzmir illerinin meteorolojik değerleri kullanılarak gerçekleştirilmiştir. Elde edilen sonuçlar göstermektedir ki çift duvar arası ısı yalıtım modeli, tüm incelenen iller ve yönlenmeler için yaz ve kış iklim şartları göz önüne alındığında ısıtma ve soğutma yükleri açısından en uygun sonucu vermektedir.

I dedicate this thesis to the loving memory of my sister.

I know you are shining down on me from heaven.

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LIST OF ABBREVATIONS

EU	:	European Union
UN	:	United Nation
USA	:	United States of America
GESR	:	Global Energy Statistic Report
OECD	:	Organization for Economic Co-operation and Development
BEP-TR	:	Energy Performance of Building Directive of Turkey
HVAC	:	Heating, Ventilation, and Air Conditioning
GDP	:	Gross Domestic Product
TOE	:	Tone of Oil Equivalent
ISO	:	International Organization for Standardization
XPS	:	Extrude Polystyrene Foam
EPS	:	Expanded Polystyrene Foam
PMV	:	Predicted Mean Vote
PPD	:	Predicted Percentage of Dissatisfied
OOP	:	Object Oriented Programming
ASHRAE	:	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
PVPS	:	Photovoltaic Power Systems Program
IEA	:	International Energy Agency

LIST OF NOMENCLATURE

μm	: Wavelength of Sunrays
Ω	: Specific Humidity
Φ	: Relative Humidity
P	: Density
C_P	: Specific Heat
K	: Thermal Conductivity
H	: Heat Transfer Coefficient
A	: Area
L	: Thickness
T	: Temperature [°C, K]
T_{sky}	: Sky Temperature
T	: Time [S]
X	: Position Vector
Q	: Amount of Net Heat Transfer
$\dot{Q}$	: Constant Rate of Heat Transfer
∝	: Thermal Diffusivity
A	: Absorption Coefficient
U	: Thermal Transmittance
I	: Solar Radiation
Σ	: Stefan-Boltzmann Constant
E	: Emissivity
T_{dp}	: Dew Point Temperature

CHAPTER 1

INTRODUCTION

With the advent of the 21st century overconsumption and depletion of available resources, disrupted ecological order due to excessive demands for energy and depletion of fossil fuel reserves have emerged as the greatest challenges that the world has to cope with as a natural consequence of the increased figures in population and industrialization. In parallel with the accentuated demand for energy, efficient use of energy correspondingly gained further significance. This in effect has driven societies to reexamine their production and consumption habits and search for alternative resources and explore novel solutions. Hence new emphasis has been rendered upon environment-friendly design approaches and creating new materials that can support energy efficiency in the buildings and industry. Concerning the current global energy problem which is one of the most urgent problems that needs to be answered, it has been proposed to replace limited and costly traditional energy resources. To solve that issue it has been suggested that heat insulation in building components provides the greatest contribution in terms of energy saving [1].

To achieve heat control by separating indoor and outside environment it is recommended to design and structure the building-facades energy efficiently. Application of heat insulation to the facades of buildings is the most significant foundation of the entire set of policies related to global energy efficiency. In Turkey, a considerable portion of energy is consumed by building sector.

As revealed by the Ministry of Energy and Natural Resources' primary data for year 2014 (Table 1.1), 73.5% of Turkish energy is met by import resources and this ratio is envisaged to rise even higher in upcoming years. Between 1990 and 2013, primary energy demand increased by 127.39%, whereas importation remained limited to 211.62%, and the rise in domestic production stayed limited to 24.78%. These figures in sum indicate a financial cost that approximately corresponds to 60 billion dollars [2].

Table 1.1. Turkey's General Energy Balance (1990-2013). [2]

Energy Data	1990	2013	Change
Total Energy Demand (million toe)	52.9	120.29	127.39%
Total Domestic Production (million toe)	25.6	31.94	24.78%
Total Energy Imports (million toe)	30.9	96.29	211.62%
Share of Domestic Production	48%	28.50%	40.63%

As a result of the increased dependency on foreign sources in Turkey, as is the case in the rest of the Earth, new regulations have been put into effect to promote the production of domestic sources and generate novel solutions. Furthermore, alternative energy strategies have also been devised in order to support the use of alternative and renewable energy resources.

Hence, provided that appropriate insulation is applied pursuant to the directive that aims to provide thermal comfort conditions by managing the energy loss stemming from the need for heating and cooling and to stabilize and continue thermal comfort, it then becomes feasible to save energy up to 50% and total energy consumption of any building can fall behind a mean ratio of 25% [3].

Due to the fact that approximately 40% of total energy consumption belongs to building sector, a growing interest has been witnessed in studies related to heat insulation in building sector in the European Union (EU). Likewise in Turkey too building sector constitutes a considerable share of energy consumption; hence it is recommended to give precedence to energy efficiency in building sector. To construct sustainable buildings, efficient use of energy and developing & applying technologies on advanced thermal insulation systems shall provide an advantage for miscellaneous sectors as well. Providing acceptable applications for the effective use of energy and thermal insulation systems should be set as one of the most critical objectives of sustainable buildings [4].

In this study's one of the primary objectives are to find out a wall model was created where the heat conduction equation was solved using implicit finite difference method. The insulation position was changed in structure of the wall.

These situations are respectively;

- Uninsulated situation,
- Inner-insulated situation,

- Outer-insulated situation,

- Center-insulated situation.

As structure of the wall is concrete and the other level of wall is XPS (extrude polystyrene foam) was employed as insulation material. This one-piece material followed the values for different insulation materials for different climates as specified in TS-825 Directive on the Thermal Insulation in Buildings [5]; hence thermal recovery and loss rates under insulation situation were computed.

And for each location of thermal insulation material energy demand might have been computed in Visual Basic program. To use as the source of data for the model developed on Visual Basic and these codes implemented within the context of data on temperature of four different cities in Turkey. The used documents which collected from Turkish Ministry of Forestry and Water Affairs General Directorate of Meteorology [6] and solar energy data which collected from Photovoltaic Power Systems Programme (PVPS) of the International Energy Agency (IEA) [7] these are;

- Ankara,

- Erzurum,

- İstanbul,

- İzmir.

Facade orientation is another important factor to determine energy consumption of the building. Also these data are conducted with direction of the buildings;

- South

- West

- North

- East

According to these variables; to design low energy house which is generally used to indicate that buildings have a better energy performance than the typical new building u value is determined based on energy regulations and standards.

CHAPTER 2

DEFINITION OF THE TERMS AND LITERATURE REVIEW

2.1. Energy Efficiency and Density

Energy efficiency means lowering energy consumption per unit service or unit product without lowering the life standard and service quality in buildings and without decreasing production quality and volume in industrial corporations [8].

In the world of economists energy efficiency corresponds to the energy level consumed to create one unit-added value and is described as “Energy Density”. To diminish Energy Density, substructure needs to be improved with technological changes; to guarantee better use of energy, certain developments should be implemented through a good organizational and management diagram and people should be motivated to use energy-efficient products.

It is revealed that in terms of both national income and energy density, the national data in Turkey point to an improvement in the years between 1990 to 2008.

However, in comparison to many other countries, (Figure 1.1) the performed change is still below desired level. This condition signifies a great potential that demands deeper analysis of energy efficiency improvements and need to climb national income level. Industry and building sectors are the sectors that provide the best opportunities for Energy Efficiency solutions. In different sectors, potential energy efficiency varies in terms of yield. In Industrial sector energy consumption in such high levels positions this sector as the target point in promoting energy efficiency investments [9].

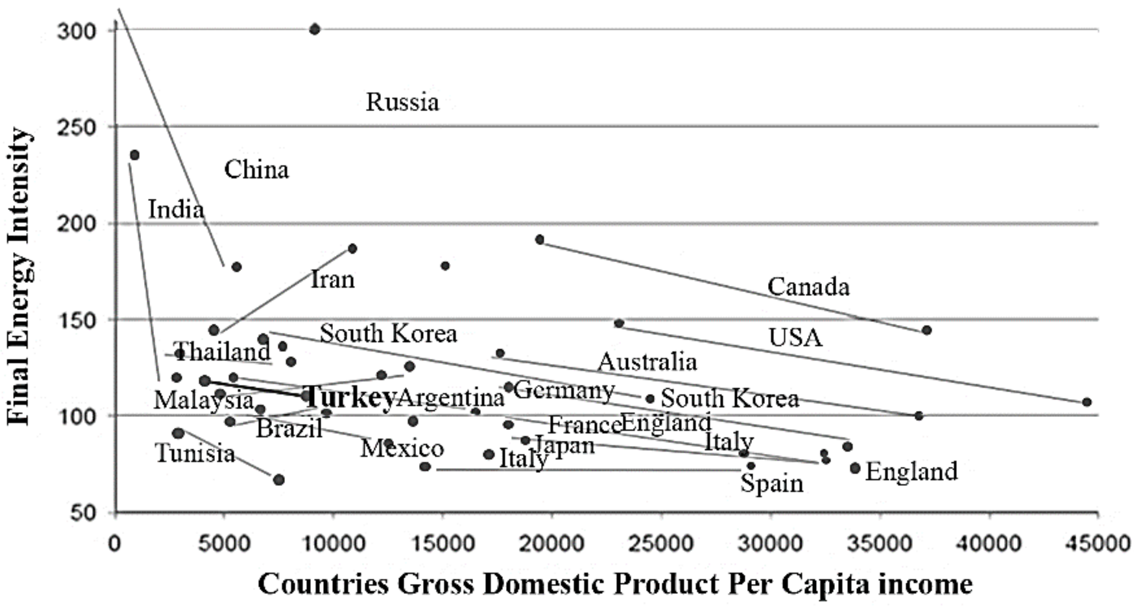


Figure 1.1. Countries Gross Domestic Product Per Capita Income According To Final Energy Intensity [9].

In recent years in Turkey, a set of laws the leading of which is the Law on Energy Efficiency have been introduced in a number of sectors and been supported via trainings. To draw the roadmap in following energy efficiency, Energy Efficiency Strategy was issued on 20.02.2012 to initiate monitoring and evaluation practices in the implementation of energy -efficiency policies.

With the issuance of the report, tangible objectives were presented and it was aimed to pull down energy density per gross domestic product (GDP) in Turkey to a minimum 20% below the mean figure of year 2011 [9].

2.1.1. Energy Efficiency in Buildings

In residences the largest portion of energy consumption is allotted to space heating. In a typical house 45% of total bill is spent for heating-cooling. In order to save the energy used to heat houses (or offices), it is required to preserve ambient temperature level inside the walls. To preserve ambient temperature level inside the walls, it is a must to keep the building effectively insulated.

The recent researches however point to the fact that buildings constructed prior to year 2000 consume twice more energy than the buildings constructed in line with current directives [9]. Significant revisions were made in the law on buildings and a directive on labeling (Energy Performance of Building Directive) was put into effect. 6-7 millions of structures demanding re-assessment bear the potential to provide energy efficiency to some level when supported by the government.

Except the primary climate zone in Turkey, maximum energy demand is 90-100 kWh/m^2.annual–on average for all new buildings in other climate zones. The same figure is 60-40 kWh/m^2.annual in Austria, 51–97 kWh/m^2.annual in Czech Republic and depending on the climate and altitude primary energy demand in new buildings is 40-65 kWh/m^2.annual in France and primary energy demand in the rehabilitation of current buildings is 80 kWh/m^2.annual. On that account, even though they comply with recent directives, energy consumption in buildings is minimum 30% above the countries that possess uniform climatic conditions [9].

2.1.2. Energy Performance in Buildings

Depending on the function of building, energy performance relates to the detection and evaluation of loads such as heating, cooling, ventilation, and lighting. The entire set of parameters which impact building energy performance is an integrated part of building energy performance and requires a holistic analysis.

Due to the increase in costs and global warming, reducing consumption ratio and boosting renewable energy resources gained further significance. Providing optimum life standards without sacrificing comfort conditions in buildings calls for, in developed countries that play the greatest role in energy consumption and in the rise in environmental pollution, effective use of energy which stands for the implementation of policies that support the use of renewable energy resources to extend the lifecycle of available resources. Within that context energy policies of the EU and Turkey should be pushed for use and relevant attempts should be stimulated.

2.2. European Union Energy Policies and Sanctions

EU has been executing a set of actions within the context of developing energy-efficiency technologies to manage energy crises, price increases in fossil fuels and to control environmental damage. “EU Energy Performance of Building Directive” (2020/91/EC) aims at achieving 20 percent energy saving as of year 2020 and meeting

20 percent of the energy need in buildings from renewable energy resources. Despite that the EU has, so as to mitigate foreign dependency in energy and decrease the consumption of fossil energy and also to keep global warming surge specified in Kyoto Protocol that was endorsed within the framework of United Nations Framework Convention on Climate Change below 2ºC in the long haul and to support the promise that as of year 2020 greenhouse emissions would be lowered to minimum 20% (30% in the event that an international agreement is signed) below the figures in 1990, the EU had to revise its Building Energy Performance (BEP) directive. The objective for December 2020 is that all the new buildings in EU member states will be with "approximately zero energy" and percentage of energy will be supplied from renewable energy resources. This revision was approved in 2009 by EU Parliament and EU Council and put into effect in April 2010 [10].

In line with this framework the preliminary issues in the scope of improving energy performance are: [11]

Measuring, monitoring and controlling the energy performance in current buildings and new buildings

Certifying the energy performance in all buildings

Periodic control of HVAC systems and tanks

Performance-based maximum values of energy consumption in buildings

Required measures to take for using low-cost systems in new buildings

Improving energy efficiency in renovated buildings.

The measurement methods are taken into consideration that; the impermeability in the body of a building (including air tightness), heating and domestic hot water, climatization systems, mechanic ventilation, lighting, the location and position of the building, passive solar energy systems and protection from sunrays, natural ventilation are some of the criteria in designing indoor spaces.

This measurement also considers the pre-determined function and age of the building. A variety of construction typologies that were evaluated within this scope have been listed to the end of identifying the standard values. Residences include business and shopping centers, education buildings (schools), hospitals, sports facilities, hotels and restaurants. In this measurement method state-conserved buildings and monuments, religious buildings, temporary buildings or buildings with temporary function are not included.

Building-related end-uses - heating, cooling, ventilation and the preparation of hot sanitary water - require approximately 75% of a residential building's energy demand [12]. Energy policies generally address these drivers of building-related consumption and it changes through this varies by country. By reducing buildings' energy consumption, a nation can reduce dependency on imported energy and strengthen its strategic position. For improving energy efficiency in buildings can greatly lessen energy consumptions with implement these rules. And this study shows us to current building energy consumption according to some principles.

2.3. Energy Policies and Sanctions in Turkey

In order to mitigate the effect of energy cost on Turkish economy "Law on Energy Efficiency" was enforced in 2007. Next, attempts were initiated to promote the use of fossil fuels towards the aim of increasing energy efficiency in buildings and next "Energy Performance of Building directive (BEP) was put into effect in 2008. The objective of this directive is to enforce the principles and practices geared towards effective and efficient use of energy and energy resources in buildings and prevention of energy waste and protection of the environment. Some of the provisions are related to mounting central heating system in all buildings larger than 2000 m^2, restricting the installation of cooling system within the limit of 250 kW and issuing an energy identity card. Within the context of energy performance this directive entails headings specified as architectural project design, principles of thermal insulation, minimum air circulation and impermeability, heating -cooling system applications, ventilation and climatization systems, sanitary hot water preparation and distribution systems, automatic control, electric wiring and lighting systems and application principles.

In the principles of thermal insulation specifically measurements are based on TS-825 "Principles of Thermal Insulation in Buildings" [5]. In this measurement the rules in computing heat energy needs in buildings and maximum values of heating energy allowed in buildings are followed. As of 2011, thermal insulation has been a legal requirement in all buildings and it has been a legal enforcement to issue until 2017 an energy identity card for existing buildings [5].

Thermal insulation applications that were applied on available residences since 2013 are now aimed to increase till 2023 by approximately 100,000 residences each year. Finally it is envisaged to apply heat insulation to about 10 million residences by year 2023 [13].

Municipalities that are required to implement and control the provisions of this directive lack the required level of knowledge and qualified personnel. Furthermore a vast majority of the existing buildings in Turkey are within the slums which translates to the fact that expenses to make for these houses would simply mean wasting financial resources. Despite the current reality in Turkey, a voluntary action is critically required to develop technology, construct low- emission buildings to set a model for the society in general, to create knowledge accumulation, to open new job opportunities, to lessen foreign dependency, and to operate domestic and renewable energy resources for the aim of protect the environment [11].

2.4. Quality of Indoor Space and Thermal Comfort Conditions

Providing indoor space comfort in buildings and corresponding jump in efficient production can be defined as a high-quality indoor environment that prevents any physiological, psychological, social and cultural discomfort for occupants. Comfort is described as the condition that enables a person to physically adapt to the environment by spending minimum level of energy and it also relates to the conditions that infuse psychological contentment with the surrounding environment. In ISO 7730 standard comfort conditions are accepted as the satisfaction of minimum 80 percent of occupants whereas in AHRAE Standard 55, it relates to the satisfaction of minimum 90 percent of occupants. In ISO 7730 and ASHRAE Standard 55 are defined indoor space quality according to some headings as below;

-Air quality and ventilation

-Thermal comfort

-Acoustics and noise

-Lighting levels

-Visual perception are some of the factors that play a vital role in ensuring environmental quality of indoor space [14].

2.4.1. Definition of Thermal Comfort

Comfort conditions vary with respect to the function of occupied residence, but still physiological characteristics such as ventilation, humidity, cooling, and heating are some of the primary qualities in offering comfort standards. These parameters identified as climatic comfort conditions designate the comfort value of any indoor space. These parameters are categorized under two main groups as personal and environmental variables [15].

-Environmental Variables: Air Temperature, Mean Radiation Temperature, Relative Air Velocity, Air Humidity,

-Personal Variables: Activity level, Clothing type

-Expectation

A list of values suggested for indoor spaces is as given below;

-Temperature of the space: 20-22 °C,

-Temperature of inner surface: 17-19 °C

-Temperature of flooring: 18-20 °C

-Temperature of ceiling: 18-20 °C

-Air velocity: ≤ 0, 2 m/s

-Relative air humidity: %40-60

-Vertical temperature difference: ≤ 3 °C [11].

2.5. Literature Review

For improving thermal comfort and reducing the energy consumption of buildings' opaque faces have significant role. Many studies deal with optimum insulation thickness depending on either heating load or cooling loads. Some authors [16 to 25] considered to calculate separately to heating and cooling loads.

Bolatturk in 2008 [16], which is analyzed to the effects of different base temperatures on the optimum insulation thickness for Turkey's hot humid climate zone with respect to the cooling and heating degree-hours. This research emphasized that optimizing the insulation thickness with respect to the cooling load was more appropriate for warm than cold regions because the thicknesses of the insulation material (polystyrene) varied between for cooling load, the optimum insulation thicknesses vary between 0.032 and 0.038 m degree-hours for cooling calculation and between 0.016 and 0.027 m degree-hours for heating calculation.

Daouas [17], investigated about dealing with determination of optimum thickness of insulation for building walls in Tunisia. Optimization is based on an economic model. A life-cycle cost analysis is carried out using two types of insulation materials and two typical wall structures under steady state conditions. An analytical method based on Complex Finite Fourier Transform is adopted for the solution of the transient heat transfer through different types of external walls. The most obvious result is the stone/brick sandwich wall and expanded polystyrene for insulation, with an optimum thickness of 5.7 cm according to Tunisia climate condition. The results show that, the most appropriate solution for stone/brick sandwich wall and EPS (0.057m). The payback period is 3.11 years also the energy savings up to %58.

Yumrutas et al. [18] are used complex finite Fourier Transform method for finding total equivalent temperature difference values of building envelope such as roof and walls. In this study which is used numerical model, to find time lag, decrement factor and solar radiation to reach results in this analytical technique. This paper is limited to the calculation of hourly heat gains and inner surface temperatures for a 24 hours' time period of one representative summer day for three types of wall structures with and without insulation.

Ucar [19] selected four various cities from four different climatic zones of Turkey, for the calculation of insulation thickness with exergetic cost evaluation. The results shows that; "the optimum insulation thickness for Antalya, İstanbul, Elazig and Erzurum are obtained as 0.038, 0.046, 0.057 and 0.0739 m respectively for the indoor temperature of 20 ◦C,. The optimum insulation thickness at the indoor temperature of 18 and 22 ◦C are determined as 0.0663 and 0.0816 m respectively for the city of Erzurum. The energy saving for the city of Erzurum is found as 77.2% for the indoor temperature of 18 ◦C, 79.0% for the indoor temperature of 20 ◦C and 80.6% for the indoor temperature of 22 ◦C, when the optimum insulation is applied."

Yu [20] determine to optimum insulation thickness on building exterior walls was analyzed which considers the effect of solar radiation on the heat transfer of building walls in winter time and summer time. Yu Investigated the optimum thicknesses of five insulation materials including expanded polystyrene (EPS), extruded polystyrene (XPS), foamed polyurethane, perlite and foamed polyvinyl chloride are calculated. In this paper the life cycle total costs, life cycle savings and payback periods are calculated depending on life cycle cost analysis. According to different orientations of wall structure, surface colors, insulation materials and also climates, optimum thicknesses of the five insulations vary from 0.053 to 0.236 m, and the payback periods vary from 1.9 to 4.7 years and life cycle is 20 years in cold climate zone and hot climate zone.

Dombaycı et al. [21] computed optimum insulation thickness by utilizing two different insulation materials and five different fuel types in city of Denizli. Dombaycı measured optimum insulation thickness of buildings' outside walls by using EPS insulation material and coal for city of Denizli situated in the III. Climate zone in Turkey. It was identified that by decreasing fuel consumption by a ratio of 46, 6%, CO_2 and SO_2 emission rates would decrease by 41, 53%. The same scholars in another study identified optimum insulation thickness for outside walls to heat buildings in Denizli by using two different energy sources and based on the number of degree-day.

Çomaklı and Yüksel [22], pursuant to TS-825 Thermal Insulation Standard in Buildings [20], measured optimum insulation thickness for the three cities situated in Turkey's IV. Zone in terms of degree-day number.

Özel and Pıhtılı [23], measured for Adana, Elazığ, Erzurum, İstanbul and İzmir cities optimum thickness for the insulation applied to outside walls by regarding degree-day values of heating and cooling. They investigated that, variety of heat flux for 5 distinct positions of insulation applying building walls has been researched numerically in the summer and winter climate conditions and insulation case for minimizing heat gain in summer and heat loss in winter was gotten. As a result of this study, the best position of the insulation for the both in summer and winter in terms of heat gain and also heat loss condition has been observed in case is three piece insulation. Three equal parts in the inside, outside and the middle on the wall structure.

Kürekçi et al. [24], by employing life cycle analysis method, conducted a study on 81 cities and measured optimum insulation thickness, payback periods and saving amounts for and outside-insulated wall model by applying two different fuel types (natural gas, import coal) and five different insulation materials (rock wool, glass wool, XPS, EPS and polyurethane).

Al-Sanea and Zedan [25], considered the impact of insulation location on the heat transfer characteristics of the building wall structure. And in this study, the thermal performance with an insulation layer set within wall was contrasted with that when the insulation layer was set on the outside. They demonstrated that the insulation layer location had huge impact on the immediate and daily mean loads under the initial transient conditions. It was suggested that for spaces where the air conditioning system is exchanged on and off intermittently, the insulation ought to be placed on the inside. The effect of insulation location on the heat transfer characteristics of building envelope and optimization of insulation thickness is investigated in many studies with implicit finite difference method.

M. Özel [26], used an implicit finite difference method under steady periodic conditions to investigate the effect of insulation location and thickness. Besides, an analytical method based on complex finite Fourier transform was used in the analyses of the optimum insulation thickness. The code is developed using MATLAB and the investigation is carried out for a south-facing wall in the climatic conditions. Wall configurations composed of (brick, insulation and plaster) outside insulation, inside insulation and middle insulation. Özel also studied the thermal characteristics of insulated walls for different wall structures, where the total thickness of brick was 20 cm (20 cm as one layer and 10 cm as two layers) and the thickness of insulation was increased from 0.5 cm to10 cm. The author supposes that the wall is coated by a cement plaster (2 cm) in the interior and the exterior surface of walls. For this, an extruded polystyrene (XPS) was selected as insulation material. While the wall analyzed, the outdoor air temperatures is used by averaging hourly measurements recorded in meteorological data over the years 2000–2010. The results indicated that the insulation location possesses a vital effect on the annual averaged time lag and decrement factor, while the optimum insulation thickness is not affected by the insulation location. The maximum temperature swings and peak load occur in the case that insulation is placed at middle of wall while outside insulation gives the smallest fluctuation. Outside wall insulation types provides the best thermal performance. This depends on the inside and outside climate also it has been demonstrated that when the insulation thickness decreases, the decrement factor increases while the time-lag decreases.

M. Ibrahim at al. [27], aim at examining the energy behavior of the buildings' multi-layer exterior wall structures. In this study's objective is to find the best wall structure and the number and position of insulation layers within exterior walls for 3 types of heating system; continuous heating, intermittent heating, and no heating operation modes. In addition in this study they analyzed a recently patented insulating coating based on the (super)-insulating materials "Silica Aerogels". Results from a transient one-dimensional heat conduction numerical model using implicit finite difference method in a multilayered wall of structure are compared to on-site measurements of an experimental set-up, having the new aerogel based coating, under real outdoor air temperature conditions. The code is developed using MATLAB, also they established that the temperature of the external surface wall is strongly influenced by the heat flow fluctuations, that transfers there through inside, during the daily variations. Inferences of this paper, a great attention should be given to the design of external walls, because their thermal properties can change significantly the indoor environment. When the outside air temperature and solar radiation vary during the day, the temperature of the external surface wall is strongly influenced by the fluctuations of the heat flow that passes there through inside.

Gagliano et al. [28], studied the effect of thermal inertia combined with natural ventilation on massive historical building wall. Estimating the heat flux within the building outside wall takes place in 1D mathematical model of transient regime with the effect solar radiation and outdoor air temperature. Numerical and experimental results showed a high potential of such combination to prevent overheating during summer. The thermal inertia of the walls depends on the thermal properties of materials such as; thermal conductivity, specific heat capacity and density. However, other parameters than walls materials may affect the thermal inertia of the building. The air change rate modifies the indoor temperature and consequently the thermal inertia.

In lights of these papers, this study the most critical objectives are to investigate a wall structure was created where heat conduction equation was solved using implicit finite difference method. The insulation position was changed to wall layer models. And also the other variance is climatic data. According to these variables it is important that to evaluate the heat flux within the building outside wall takes place in one dimensional mathematical model of transient regime with the effect solar radiation and outdoor air temperature.

CHAPTER 3

DESIGN CONSIDERATIONS FOR ENERGY EFFICIENCY

3.1. Climatic Data

Climatic air temperature stands for the mean value of weather events such as air humidity, air movements and solar radiation. Geographical position, altitude above sea level, quality of atmospheric layer, topography and surface cover are some of the physical factors effective on climate. In addition physical attributes of the surface tools of outside spaces and environment and geometrical features such as shape, dimension and position of environmental structures and other components are also influential on climate.

Climate components that form weather conditions in outside environment are solar radiation, outside air temperature, outside air humidity and wind (air movements). These are the data that are effective in the conservation of building energy and comfort conditions [29].

3.1.1. Solar Radiation

Radiation is the energy that is emitted from particles in the form of electromagnetic waves (or photons) as a result of the changes in the electronic patterns of atoms and molecules.

Sun is the main source of energy. The energy radiated from sun is called solar energy and this energy, upon interacting with the atmosphere, reaches its final destination in the form of electromagnetic waves. Solar radiation is the radiation energy that occurs after the continuous fusion that takes place when two hydrogen atoms form a helium atom. Electromagnetic waves spread over quite a wide spectrum in a variety of wave lengths and intensities.

1.373 J is per second average value of solar energy that is radiated onto a space of 1 m^2 that is directly perpendicular to solar energy. This value is termed as “Solar

Constant - GSC". Also known as total solar irradiance, solar constant indicates the velocity of solar energy that perpendicularly reaches to a space in the periphery of atmosphere when globe is on an approximate distance from the sun. Wavelengths of sunrays vary between 0, 1-3 μm. Distribution of sunrays is such: 9% is in ultraviolet zone, 39% is in visible zone and the remaining 52% is in infrared zone. Light is the visible radiation energy that is between 380-750 nm of wavelength which is favorable for the sensitive human eye and is located within electromagnetic spectrum [30].

Solar radiation affects building envelope from two aspects. Once short-wavelength solar radiation reaches to indoor environment from transparent surfaces it is absorbed by the surfaces inside the building, thus transforming into long-wavelength thermal radiation. Limited amount of solar radiation sent to opaque surfaces of building envelope is reflected and the rest amount is absorbed. The energy stored in this massive surface is transferred via conduction, convection and radiation.

As regards solar radiation from building envelope; absorptivity, reflectivity and transparency are the optic factors that determine saving in solar energy. Heat conduction coefficient, heat storage capacity, heat radiation capacity, time lag and damping ratio are the thermophysical qualities that determine the amount of saving in solar energy [31].

3.1.1.1. Solar Radiation Behaviors at Opaque Surface

Some amount of solar radiation that reaches an opaque surface is reflected whilst the rest is absorbed by the surface. When outside environment temperature is higher than surface temperature, surface temperature rises above outside environment temperature and heat loss occurs from the surface to the environment.

The amount of energy lost from the surface through radiation is directly proportional to the increase in surface temperature. With the climb in surface temperature, heat is stored within the body of material and heat flow happens directly to the inner surface.

Thermal energy having reached the inner surface is transmitted to the indoor space via conduction, convection and radiation. Such characteristics of selected material basically play the most important role in space organization and mass formations in providing conditions for indoor space comfort.

3.1.2. Outside Air Temperature

Intensity of solar radiation, the effect of the change witnessed in solar energy when passing through the atmosphere, properties of the surface, interaction between the earth and atmosphere; levels of energy change in events such as evaporation, fusion and freezing; air movements and the direction and intensity of sea flows; vertical transfer of energy via convection and turbulence and altitude are the factors that trigger differences in the annual mean temperatures of residences even if they were located in identical latitudes. That accounts for the reason why long-term annual climate data need to be evaluated [32].

Turkish Republic General Directorate of State Meteorology Affairs conducts measurements on outside environment temperature values in weather stations located in the regions [31]. These measurements provide hourly, daily, monthly and annual data on the mean, minimum and maximum temperature values.

3.1.3. Sky Temperature

"The sky can be considered as a blackbody at some fictitious known as sky temperature (T_{sky}) at which it is exchanging heat by radiation from a terrestrial body" [33]. When calculation of sky temperature it must be known that, not only varies hourly but also from place to place and on condition of sky. Many correlations are proposed to calculate T_{sky} for clear skies in terms of measured meteorological parameters. T_{sky} is directly associated with outside air temperature and dew point temperature. The effect of sky radiation can be accounted for approximately by taking the outside temperature to be the average of the outdoor air and sky temperatures.

3.1.4. Humidity

There are several gases in atmospheric air. Some of these gases are constant and in fixed ratios whereas some gases change depending on several factors in due course and place. Amid these gases water vapor is the most critical unstable gas with respect to climate and building physics and water vapor inside air is defined as humidity.

Humidity ratio in weather is expressed as "relative humidity" or "saturation of fraction" and shown in % (percentage). In all levels of temperature, there is some amount of water vapor inside air and it affects building element. Air without water vapor inside can only be obtained under experimental conditions and be labeled as "dry air". Under no circumstances can water vapor volume exceed 4% of air volume. Depending on air temperature and water vapor saturation level of the air, water vapor absorption capacity of the air varies [31].

Specific humidity (ω): It relates to the mass of water vapor inside the dry air in a unit mass. It is also called as humidity amount of moist air or mass concentration and its unit is specified as kgH^2O/kg dry-air.

Relative humidity (ϕ): It relates to the ratio of water vapor in the air within a specific temperature by maximum amount of water vapor that can be detected inside the air under very same conditions. It is expressed as % (percentage).

Humidity can negatively impact energy performance by causing such damage in building envelope materials and components. Hence in selecting interior building materials and envelope materials in particular, specific attention needs to be paid to the amount of rainfall, flora, wind effects, altitude above sea level and several geographical and climatic conditions in the zone of the building [3].

3.1.5. Wind

As a product of the differences in pressure that emerge in climatic events, wind is a crucial climate component that plays role in the control of climatic comfort. Wind has several effects on buildings: static effects relate to pressure and snow load; dynamic effects relate to vibration; environmental effects relate to health; comfort effects relate to heat transfer, pollution and noise distribution, fire spread, rain and air leakage.

Such effects of wind on the buildings manifest themselves depending on;

-Direction and characteristics of the blow (hot-cold, dry-damp),

-Velocity (velocity increases as pressure differential rises),

-Duration of blow,

-The relation of building with the ground (elevated or buried or on the same level with the ground),

-Format of the building (compact, courtyard or free-range emptied),

-Properties of surrounding structures, topography and plant cover,

-Tissue of the interacted surface (ruggedness).

Since the velocity of wind increases proportional to the rise in height, buildings loss or gain heat. Heat convection coefficient value which also depends on the wind velocity is an important parameter in built environment organization however the position of buildings to each one bears in itself certain characteristics that decrease or increase the management of this climate component and decrease or rise the level of energy consumption. For instance, in order to benefit from the cooling effect of wind in designing a building site, buildings need to be positioned within distances that do not trap the structures into wind's negative pressure area [34].

In cold and mild-dry climate zones, due to its wind-protection priority during the minimum hot periods, the aim is to minimize energy losses. In hot-humid and mild-humid climate zones the aim is to minimize cooling loads by utilizing cooling effect of the wind during the hottest periods. In hot-dry climate zones on the other hand it is required to minimize heating and cooling loads by protecting oneself from the wind in the minimum hot period and in the hottest period by utilizing the wind if the wind already has a cooling character.

3.2. Different Climatic Zones in Turkey

Differentiation in one or some of the parameters such as temperature, rainfall, humidity, length and intensity of insolation, pressure, direction and velocity of wind and evaporation that collectively form climate can lead to the formation of a variety of climate types. Once the areas that manifest identical or similar climatic characteristics are classified, different climate zones are obtained.

In order to gather data on the climatic characteristics of any place it is necessary to conduct 35-40 years of climate observation at minimum. In Turkey climate observations are dated to 1925. Till present day an abundance of climatic classification systems have been introduced globe wide and a large number of these systems are founded upon latitudes, temperature types, rainfall and natural vegetation. Wladimir Köppen's classification is the most popular one of all the others. According to his system there exist 5 main climate groups (tropical, dry, mild, cold and polar climate).

In a range of studies within the scope of altitude, sea distance, mountain ranges and several geographical properties as well as data on built environment Turkey's climate zones have been analyzed under a number of classifications as below;

In Zeren's (1978) researches; 5 zones as cold, mild-dry, mild-humid, hot-dry and hot-humid [35].

In Ayan's (1985) research; 5 zones as cold, mild, Mediterranean, hot-humid and hot-dry,[36].

In Orhon's (1988), Gürsel's (1991), Karaman's (1995), Göksu's (1999) and Akşit's (2005), research; 5 zones as hot-humid, hot-dry, mild-humid, mild-dry and cold [37,38,39,40,41].

Within the context of present research, above mentioned studies were examined and by adhering to TS-825 standard [5] as well, pilot cities were designated. With the contribution of analyzed studies, 4 climate zones in total were analyzed. Turkey has been classified into 4 insulation zones as per TS-825 standard (Figure 3.1) [5] according to their level-day (DG) figures. 1st zone stands for the zone that needs the least amount of energy; 4th zone stands for the zone that needs the highest amount of energy. In terms of this standard İstanbul was selected as the pilot city for mild humid climate zone (Marmara Region), Erzurum was selected as the pilot city for cold climate zone (Eastern Anatolia Region), Ankara was selected as the pilot city for mild- dry climate zone (Central Anatolia Region), İzmir was selected as the pilot city for hot- humid climate zone (Aegean Region).

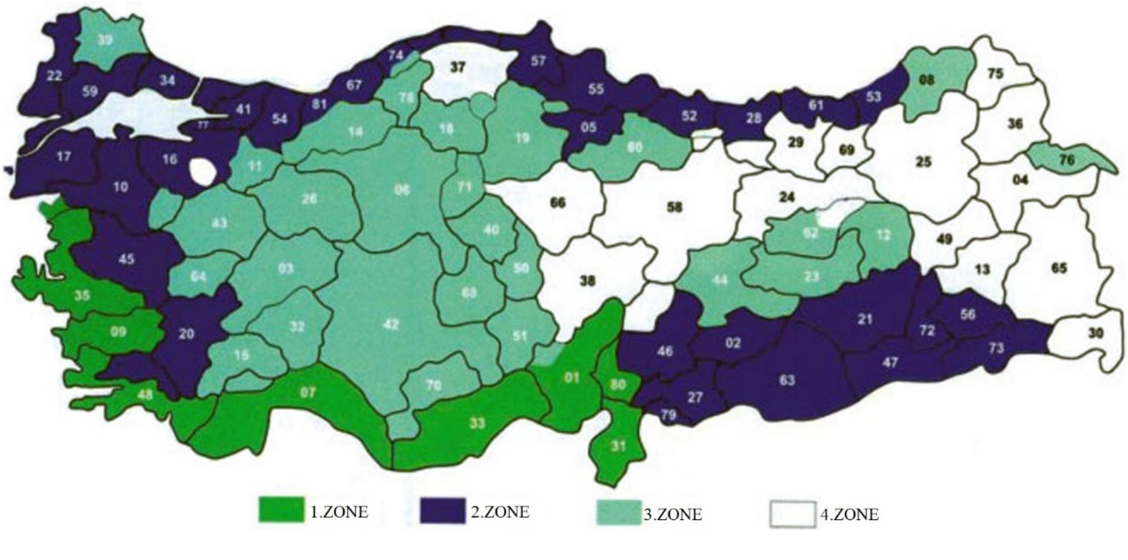


Figure 3.1. Turkey Climate Zones. [5]

3.2.1. Cold Climate Zone

In a cold climate zone temperature points to below 0 ºC in nearly half of the year and the winters are long and harsh. The lowest mean temperature in this zone is around -20 ºC. Precipitation is in the form of rain during summer months and in the form of snow during winter months. Snow fall generally starts in October and lasts until the mids of May, but summer season is short and cool. Amount of rainfall is low and relative humidity is also below standards. Harsh climate conditions become even tougher due to wind’s effect [40].

“Ağrı, Ardahan, Bayburt, Bingöl, Bitlis, Bolu, Erzurum, Gümüşhane, Hakkâri, Kastamonu, Kars, Muş, Sivas, Tunceli, Van and Yozgat are located in cold climate zone [37, 41].” In this study which is selected Erzurum city from cold climate zone.

3.2.2. Mild-Humid Climate Zone

Summers are mild, winters are moderately cold. There is not any harsh winter season or extremely hot summer months. This zone can be described as the climate that demonstrates the most favorable conditions for human comfort since temperature variation in summer and winter months is basically negligible. Still, depending on the altitude and position with respect to sea level, it is likely to detect minor or major temperature differences during summer and winter months. Rainfalls are distributed among the seasons and mostly experienced during January, February and June. The hottest months are July, August and September. The most significant characteristics of this climate is that amount of rainfall and humidity is high. [40]

“Amasya, Artvin, Balıkesir, Bartın, Bilecik, Bursa, Çanakkale, Düzce, Edirne, Giresun, İstanbul, Karabük, Kırklareli, Kocaeli, Ordu, Rize, Sakarya, Samsun, Sinop, Tekirdağ, Tokat, Trabzon, Yalova and Zonguldak are located in Moderately-humid climate zone [37, 41].” In this study which is selected İstanbul city from mild humid climate zone.

3.2.3. Mild-Dry Climate Zone

In a mild-dry zone there is huge difference in day & night temperature values and mean outside temperature varies from +30ºC to -5 ºC. Rather than the altitude, this differentiation is driven from the presence of mountains that block sea's cooling effect during summer and warming effect during winter months. Summer nights have a cool nature and mean temperature is 27-37 ºC. Mean temperature in winter is around 8-15 ºC [40].

"Afyon, Aksaray, Ankara, Burdur, Çankırı, Çorum, Elazığ, Erzincan, Eskişehir, Iğdır, Isparta, Karaman, Kayseri, Kırıkkale, Kırşehir, Konya, Kütahya, Malatya, Nevşehir, Niğde and Uşak are located in moderately-dry climate zone [37, 41]." In this study which is selected Ankara city from mild dry climate zone.

3.2.4. Hot-Humid Climate Zone

The most significant characteristics of hot-humid climate are intense rainfall, high ratio of humidity and hot weather. Temperature difference between summer and winter months is negligible. There is heavy rainfall during winter months. Dominant wind or air currents between mountains-lowland, sea-land has the desired qualities. [40]
"Adana, Antalya, Aydın, Denizli, Hatay, İzmir, Manisa, Mersin, Muğla and Osmaniye are located in hot-humid climate zone [37, 41]." In this study which is selected İzmir city from hot humid climate zone.

3.3. Structural Data

On building scale, a set of design parameters play effective role in managing the effects of outside climate component on building envelope to minimize the energy loss of climatic comfort conditions.

- Position of the building
- Position of the building with respect to other buildings
- Dimensions and form of the building
- Direction of the building

3.3.1. Position of the Building

Position of the building is an influential parameter in tandem with the slope of land piece, position, vegetation and direction in climate control and prevention of air pollution. Once these parameters are correctly appointed it becomes feasible to further increase the efficiency in passive system applications and reduce the level of environmental emissions.

Prior to selecting residential zones climatic analyses of the zone should be conducted and climatic character of the zone should be established. In line with that detection the position should be identified according to the thermal zone of the piece of terrain. Additionally slope analyses should be implemented on the land and different methods of direction should be identified for surfaces with dissimilar slope angles [42]. In mild-humid climates it is of vital importance to benefit and shelter from the sun and the wind. Therefore it is necessary to settle in the peak surfaces of slopes.

In hot-dry climate zones it is necessary to settle in valleys to be protected against solar radiation.

In cold climate zones it is necessary to settle in sun-facing surfaces of the slopes in order to maximize the benefits of the sun and protect from the wind [43].

3.3.2. Position of the Building with Respect to Other Buildings

Position of the building greatly matters in order to ensure that during winter season maximum benefit is received from the sun and during summer minimum benefit is received and air movements are utilized to obtain the optimal benefit. On that account solar radiation and velocity of air movement vary with respect to the distance from nearby buildings, height and position. If it is aimed to benefit in maximum level from solar radiation the distance between buildings should be equal to the maximum shade length of nearby buildings and other barriers.

Considering the properties of the climate zone in which the building is located, it should be specified whether to benefit and/or protect from solar radiation.

In order to benefit from solar radiation, distance between buildings should be identified on the basis of factors such as sun's motion, land slope, direction and intensity of occupancy.

Under hot climates and hot air conditions which require protection from solar radiation it is vital to plan the buildings in a way to lay shadow to each other and prevent the long-term reflection of sunrays all day long [44].

3.3.3. Dimensions and Form of the Building

The vertical and horizontal dimensions of the building are the variables that determine surface area of the building envelope. These variables correlate with total surface area of the building, building's total and differently directed roof surface areas and facade ratios. The form of the building is described with geometrical variables such as building height, roof type, and roof slope [45].

Since indoor surface temperature of envelope is not identical to the temperature of other surfaces, the shift in envelope area triggers a change in the mean radiational temperature, amount of heat that passes through envelope component which in effect drives a change in the temperature of indoor environment [42].

In parallel with the changes in climate zones, form and size of buildings should also be altered to maximize energy recovery. In the period when heating is undesired, minimum heat recovery should be provided but when heating is desired maximum heat recovery should be provided.

In cold climate zones it is necessary to create designs that can maximize the benefit from the reflective effect of sun during the minimum hot period; that can protect against dominant wind and provide heat protection inside the building [34].

In the building design of these climate zones, surface volume ratio is vitally important. The building should be designed in a more compact form to occupy minimum surface area and to benefit from sunrays in maximum level. In such buildings the greatest concern is about the application of isolation. Based on the type and thickness of selected isolation material U value (overall heat transfer coefficient) should be maximum $0.5 W/m^2K$. Windows should be small in size, transparent surface area should be shrunk and windows should be double-glass at minimum and three glassed and glazed preferably or filled with low-e plated inert gas (like argon) [46].

Mild-humid climate zones necessitate the kind of designs that can, during the hottest period, mitigate the discomfort of high humidity and heating effect of the sun; but during the minimum hot period it should offer wind protection and heating through sunrays [34]. Wind should be utilized as a factor that can alleviate undesired intensive humidity effect of the climate. In such climate zones, independent plans with strong connection to indoor and outside spaces should be devised and buildings should face southeast and southwest but not the west and east direction.

In mild-dry climate zones, during the minimum hot period, it is required to increase the heating effect of solar radiation but decrease cold wind effect whereas in the hottest period it is required to benefit from the cooling effect of the wind [34].

In cold climate zones, under the conditions of this climate too, more surface-compact buildings should be designed by considering volume surface ratio and the buildings should be positioned on the east-west axle of the lower sections in slopes.

In hot-humid climate zone, the measures that minimize heat recovery and radiation during the hottest period increase humidity loss and ventilation but during the minimum hot period that can provide heat protection it will be sufficient to create optimum comfort conditions [34].

Under such climatic conditions, buildings should be sporadically positioned to benefit from air flow and the parts that receive the strongest wind should be the settlements to select. Tall and high buildings should be chosen and designs should predominantly be positioned on the east-west axle.

In hot-dry climate zone, measures that increase humidity ratio and shading during the hottest period and offer protection against dry nature air movement (if air movement has humid nature it should be utilized) but increase the heating effect of solar radiation during the minimum hot period gain further significance [34].

In the designs to build in such zones yard-type buildings should be opted for in order to minimize heat recovery and increase humidity ratio and to offer protection against radiation the buildings should be intensely and shady designed. Building surfaces should be white and on west, east and south facades, transparency ratio should be reduced and shaded design can be used [46].

3.3.4. Direction of the Building

In the direction of a building effective wind and sunrays should be appropriately utilized and protected against. Thus it is one of the key objectives to benefit from the effect of dominant wind to obtain natural ventilation. Wind velocity and type of airflow also vary with respect to the dimensions and inter-positioning of the barriers encountered at the direction of wind blow [47].

Based on such behavior of the wind, the distance between wind-blocking buildings and analyzed building, heights of the nearby buildings, their positioning with respect to this building and landscape around the structure are the factors that play role in the effect of the wind [48].

3.3.5. Significance of Building Envelope

Building envelope is designed in a way to meet the user's needs for health, comfort, safety and economy and combine a range of factors such as durability, resistance, functionality and aesthetics. It is designed depending on the prevailing atmospheric conditions, mechanic behaviors of the structure elements individually and collectively, the properties of the materials and function of the structure. The elements constituting a building envelope are grouped under five categories according to climate zone as below; [49].

- Concrete components,
- Walls,
- Doors and windows,
- Roofs,
- Flooring or walls that contact the ground.

In order to meet the requirements for health and comfort, in designing a building envelope, main criteria such as heat, noise, humidity, fire and light are observed (Figure 3.2). In addition to such criteria building envelope is designed in the best way to provide comfort requirements by also considering the function of the structure and natural environment. Climatization systems selected to provide comfort requirements depend on a number of variables among which are lifecycle of selected place, use period, function of the place etc. [50].

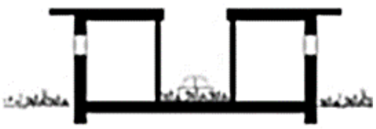
Hot Humid Climate Zone		Walls: Heat storage capacity is low, light color, sunlight reflectivity is high, lightweight construction. Windows: Allow air movement between the inside and outside, outdoor shading devices actually shade the window from direct radiation, large openings. Roof: The sloped roof allow free air movement.
Hot Dry Climate Zone		Walls: High heat storage capacity, massive walls Windows: Large windows onto courtyard and small openings in the exterior wall. Roof: Reduce the thermal impact of solar radiation of flat roofs
Temperate Climate Zone		Walls: to provide comfort condition in the interior space with an insulation. Windows: Openings are large enough to provide the necessary temperature control. Roof: Isolated pitched roof.
Cold Climate Zone		Walls: High heat storage capacity, well-isolated massive walls. Windows: Well-isolated, multi glazed openings. Roof: well-insulated pitched roof.

Figure 3.2. The Elements Constituting a Building Envelope are Grouped According to Climate [50].

CHAPTER 4

PROPERTIES OF BUILDING ENVELOPE

4.1. Properties of Building Envelope which Affects Energy Performance

Thermophysical properties of building envelope, when combined with the effect of heating system, play critical role in the determination of heat amount passing through opaque and transparent components of the envelope as well as indoor air temperature and indoor surface temperature that occur in volume. These are at the same time the properties that define facade envelope in terms of passive climatization function.

In terms of passive climatization function, definition of facade envelope is given with respect to envelope's properties below; [51]

- Thermal conductivity, heat transfer coefficient, specific heat, density, ratio of transparency, time lag, amplitude decrement factor and similar thermophysical properties.
- Absorptivity, transmissivity, reflectivity and similar radiative properties concerning solar radiation;

Radiative and thermophysical properties of building envelope play determinant role in the heat amount recovered or lost from the unit area of building envelope due to the effect of indoor and outside air temperature and solar radiation. Indoor climatic conditions as well as heating and climatization loads display changes depending on the total heat amount recovered or lost from building envelope. Hence radiative and thermophysical properties are the determinants of indoor climate conditions as well as heating and climatization loads [2].

4.1.1. Radiative Properties

Attenuation, absorption and scattering coefficients respectively represent the amounts of solar radiation absorbed and reflected by the component with respect to the solar radiation reaching to outer surface of the component. Solar radiation reaching to outer surface of building's façade transform into solar heat recovery based on the radiative properties of the materials on the facade [51].

Outer surface's absorption rate of solar radiation is directly proportional to the heat storage of the system. Darker colors have higher ratios of absorption and but they have small ratios of reflection. The situation is opposite for lighter colors. Thence black is the optimum color for thermal storage. Heat loss through radiation to the outside environment from dark color surfaces is substantial since applied paints have greater effects in emitting long wavelength radiation.

4.1.2. Thermophysical Properties

Outer envelopes of the buildings are vulnerable against outside climatic conditions that continuously vary through the day and these are environmental temperature and solar radiation. Once outer surface of the opaque wall of a building is under the effect of solar radiation, until a new equilibrium is set under novel conditions, there is a variation in temperature alongside the wall thickness [2].

The process that lasts till this new equilibrium is set depends on the time interval. Before the breakout of radiation absorption distribution of temperature inside the wall is in equilibrium conditions and displays a linear change. The slope in temperature distribution and border conditions depend on temperature difference between inner volume and environment and thermophysical properties of the wall.

Elements such as thermal radiation coefficient and heat storage capacity are the parameters effective in transferring the heat inside the material from outer surface to inner surface.

Heat quantities lost and gain on unit area of facade envelope vary with respect to the properties of heat insulation, thereby changing the heating and cooling loads with respect to particular thermophysical properties. As regards the building envelope forming the facade, the decrease in thermal insulation resistance leads to increased heat losses in winter to the outside environment which in effect climbs fuel expenses,

In the failure of providing thermal comfort conditions inside, some negative outcomes occur such as health detriments for user's health and decreased performance for the user.

In order to minimize such negative consequences heat insulation can be applied to control the heat flows between indoor and outside environment. There is correlation between designing energy-efficient building facades and enabling the heat insulation to manifest the desired level of performance. Designing the building facades as energy-efficient systems by minimizing their heating & cooling energy costs entails the process of identifying optimum values for the above-explained building parameters. Such plan allows the practitioners to design and construct the building in a way that minimizes energy costs not only during usage but starting from designing process [4].

4.2. Heat Insulation for Saving the Energy of Building

In the case that users' thermal comfort in buildings is secured, the need for artificial-heating gains further significance since its gravity for user performance and work efficiency has been better understood nowadays. However gradual decrease in the resources used for artificial-heating and the corresponding rise in costs, conservation of heating and cooling energy in buildings and use of thermal insulation material have recently been added to the agenda.

Among the reasons that enforce using thermal energy in buildings are thermal comfort needs and insufficient natural heating which in effect leads to using extra thermal energy in buildings that inevitably results in a rise in fuel consumption.

Thermal comfort need is a biological demand that enables a person to sustain his/her life climatically, maintain his/her well-being and boost his/her work performance. Comfort can, despite individual differences with respect to personal factors, reasonably be defined in terms of physiology as humans' adaptation to the environment through minimum level of energy and psychological contentment with his/her surrounding.

To secure user health and comfort in any given artificial environment it is of necessity to continuously provide thermal comfort conditions. In the period artificial heating is demanded, the difference value between outside air temperature and indoor air comfort temperature determines the amount of heating need or thermal loss of the building. Provided that indoor air comfort temperature inside any building block can be sustained under a specific air temperature in the outside environment, it indicates that heating need is met satisfactorily. Due to the significant difference between indoor and outside air temperature, it becomes a necessity to meet indoor environment comfort conditions via artificial heating methods in lieu of natural methods.

The gradual increase in artificial heating energy expenses corresponded to a jump in the global energy consumption, which in effect introduced a threat of the depletion of energy resources. On that account there is an urgent need to minimize using energy resources and seek alternative, natural-energy resources. Minimizing artificial heating energy costs shall translate to minimizing thermal losses in the buildings which would in effect introduce the use of heat insulation.

4.2.1. Heat Insulation

Heat insulation is used, for the purpose of yielding indoor thermal comfort conditions, to block heat flows from inside to outside or from outside to inside according to the intensity of outside climatic conditions; to prevent the negative effect that might arise due to the temperature difference between indoor environment and outside environment; to minimize heating and cooling energy costs in consequence. In order for thermal insulation materials to perform in the way they are expected, they should be designed after paying heeds to the external factors (wind, temperature, humidity…) affecting the design of the building elements they are installed in.

There is an immediate correlation between ensuring indoor environment comfort conditions in buildings and selecting the appropriate thermal insulation materials to use. To establish thermal comfort, thermal insulation materials create a mitigation effect on the heat transmission between different environments. In the materials to use for thermal insulation purposes, thermal conductivity coefficient needs to be below a certain level.

Thermal conductivity coefficient value is not adequate in the selection of insulation materials. The accompanying properties in the selection of insulation materials are including but not limited to humidity absorption, specific heat, thermal expansion coefficient, temperature and steam resistance, mechanic resistance, density, infestation resistance, odorlessness, workability, and low-cost. In Table 4.1. [52], Expanded polystyrene, extrude polystyrene, mineral wool from slag, mineral wool from rock is analyzed in the following headings: Low and constant thermal conductivity, resistance to different weather conditions, prevent corrosion and breaking down of the insulated object, flexibility, long-life cycle, sound proofing.

Table 4.1. Properties of the Thermal Insulation Materials [52].

Name of the group of the thermal insulation material	Properties of the thermal insulation materials					
	Low and constant thermal conductivity	Resistance to different weather conditions	Prevent corrosion and breaking down of the insulated object	Flexibility	Long life cycle	Sound proofing
Expanded polystyrene	Can be decreased due to absorbing the water due to open structure of the pore, and a lot of free space in structure	Should be protect from water, due to open structure of pore. Also from high temperatures (higher than +750C) due to raw material, which can't withstand high temperatures. Material can't be used as air barrier.	Should be insulated from different kinds of iron structures, because, material can provide water and cause the corrosion of the steel structures.	Has a low opportunities to flexibility, due to during the manufacturing process, object of the heat treatment are separate particles of polystyrene. So, the contact between particles of polystyrene is	Live cycle can be decreased due to contact with water, deformation of the construction, or contact with different substances which are based on solvents	Can't be used as sound proofing, but it's sound proofing properties are better than extruded polystyrene. Because pore are open, and they are big (0,3-0,4 mm). But structure of the material is too hard to absorb the energy of sound wave
Extruded polystyrene	Can save it's thermal conductivity on a constant level during the life cycle of the insulated object, due to closed structure of pore and absent of free space inside the material.	Have a high level of the resistance to weather conditions due to closed pores and absent of free space in inside. Also can be used as air barrier, due to possibility of sealing between the lists of the material. But, also should be protect from temperatures higher than +750C	Can protect insulated structure from corrosion, because, this material don't absorb water. Also can protect different kinds of insulated structures from outdoor impacts.	Has a high opportunities to flexibility, due to during the manufacturing process, object of heat treatment is a single mass of polystyrene. So, the contact between particles of structure is very strong, and can withstand deformations.	Live cycle can be decreased due to contact with different substances which are based on solvents	Can't be used as sound proofing, because pore are closed, and they are too small (0,1-0,2 mm). And the structure of the material is too hard to absorb the energy of sound wave

(cont. on next page)

Table 4.1. (Cont.)

Name of the group of the thermal insulation material	Properties of the thermal insulation materials					
	Low and constant thermal conductivity	Resistance to different weather conditions	Prevent corrosion and breaking down of the insulated object	Flexibility	Long life cycle	Sound proofing
Mineral wool from slag	Can be decreased due to absorbing the water due to spongy structure. Because during the manufacturing process many fibers are glue with each other and form structure with a lot of big and communicated with each other pore, with a lot of free space with each	Can't prevent harmful influence of weather conditions, so it should be protect from wind, snow and water by other protecting materials. Application temperature is up to +400°C	Can't prevent the corrosion of iron structure, due to absorbing the water. So it should be separate from iron structures. Also this material can have a harmful influence for other surrounding materials. Because it can keep absorbing water for a long time, and harm other constructions	Has a high opportunity to flexibility, because it consist of fibers, which a flexible. But Flexibility increases while density increases.	Life cycle can be decreased due to absorbing water. Also if mineral wool with low density (<100 kg/m3) will put into walls, it will clod.	Mineral wool with low density (<100 kg/m3) is very good material for sound proofing. So, when sound wave contact with it, it can absorb energy of the wave. Also, a lot of big (1-5 mm) pore, communicated with each other, give a good effect. It's good to insulate from impact noise, and vibrations.
Mineral wool from rock	Can be decreased due to absorbing the water due to spongy structure. Because during the manufacturing process many fibers are glue with each other and form structure with a lot of big and communicated with each other pore.	Can't prevent harmful influence of weather conditions, so it should be protect from wind, snow and water by other protecting materials. Application temperature is up to +800°C.	Can't prevent the corrosion of iron structure, due to absorbing the water. Also this material can have a harmful influence for other surrounding materials. Because it can keep absorbing water for a long time, and harm other constructions.	Has a low opportunity to flexibility, because it consist of fibers, which a not flexible (raw material is rocks). Also density of such materials are usually high (>100 kg/m3), which is not good for flexibility.	Life cycle can be decreased due to absorbing water. But this kind of material isn't clod, because fibers are thicker, and density is high enough (>100 kg/m3)	Such mineral wool with high density (>100 kg/m3) is very good material for sound absorption, which consist of fibers, which connections with each other is harder than in mineral wool from slag. So this material is better to use for insulation from noise.

4.3. Types of Thermal Insulation Materials

According to the position in structural elements they are divided into two;

-Thermal insulation around the building envelope (insulation sandwich wall with interior and exterior)

-Thermal insulation within the building envelope (insulated paint, mortar, concrete, walls ...) [49].

They can be classified in to three categories in which they exist in nature;

- Plant-based thermal insulation materials
- Animal-based thermal insulation materials
- Mineral-based thermal insulation materials

Also the insulation materials are divided according to artifact structure into four parts;

- Thermal insulation materials with grained structure
- Thermal insulation materials with fibrous structure
- Thermal insulation materials with foam structure
- Thermal insulation materials with a composite structure

Thermal insulation materials are separated in 2 groups in terms of solar radiation;

- Opaque thermal insulation materials
- Transparent insulation materials

4.3.1. Natural Thermal Insulation Materials

“Plant-based thermal insulation materials; cork plate and grains, soft wooden chip plate, corrugated board, turnip, nutgrass, cane, linen, cotton, coconut, palm fibers, hay, paddy husk(rice crust), and miscellaneous algae.

Animal-based thermal insulation materials consist of the hair and wool of several animals which provide wool, goat hair and angora.

Mineral-based thermal insulation materials; this group entails rockwool extracted from basalt stone and glasswool extracted from silicium-based glass”. These are open-porosity, thermal insulation materials in which polymer binders are frequently used in order to change the glass or stone into fiber for adherence to one another after the melting process [49].

4.3.2. Artificial Thermal Insulation Materials

This group encompasses plastics-based thermal insulation materials produced from different polymer groups. These materials can be open or close porosity; can manifest a rigid or flexible form and exist in different concentrations.

Thermal insulation materials with grained structure; perlite, vermiculite, fossil siliceous grains and expanded cork.

Thermal insulation materials with fibrous structure; plant and animal based fibrous thermal insulation materials and mineral-based fibrous thermal insulation materials which are produced from organic and inorganic fibers and utilized to minimize heat conduction.

Thermal insulation materials with foam structure; open or close porosity structured, mineral and synthetics based thermal insulation materials belong to this group. Gas concrete, pumice stone, glass foam are within this group.

Thermal insulation materials with a composite structure; it is one of the most common methods of increasing thermal insulation performance. Binder agent agglomeres such as perlite concrete, expanded cast, and bitumen binding expanse cork can be created in a set of combinations such as cement binding wood dust, bakalite glass wool, asphalt binding glasswool and similar composites equipped with fibers [38].

4.3.3. Thermal Insulation Materials in terms of Solar Radiation

Opaque thermal insulation materials; opaque building elements are composed of building components that either absorb or reflect the sunlight. These components are structured in a way that neither conducts sunlight nor allows visibility for the objects positioned behind. A vast quantity of traditional thermal insulation materials (glasswool, rockwool, polystyrene foams) fall into the category of opaque insulation materials.

Transparent building elements exhibit properties of absorbing, reflecting and conducting the sunlight. Thanks to its semi-conductivity feature, it also enables visibility for the objects located behind. For the aim of benefiting from the sun in a building envelope, these materials are applied to outer façade[49].

4.4. Outside Wall System and Its Properties

In addition to the differences of applications and properties in every single building element (outside wall, roof, floor, window…) constituting the building envelope, there are also divergences in the specifics and forms of application.

The completed works indicate that in building elements, maximum amount of thermal loss occurs in outside walls. Besides, failures in correct application methods also lead to further thermal losses in outside walls. Hence defects in insulation applications trigger an increased fuel consumption each new year. If we assume to exist 100% thermal loss in an uninsulated wall, this ratio can be pulled down to 40-60% with an average insulation application and to 15-35% with a sufficient insulation application [53]

Building outside envelope forms the border between indoor environment and outside environment. Building elements that form outside envelope are respectively lined as exterior wall, roof, open-bottom flooring, basement walls and ground-flooring.

With the introduction of novelties in building technology, homogenous and thick building envelope used in traditional systems has lost its bearing-function particularly in concrete and steel cage systems. In such systems, outside walls that constitute a substantial portion of building envelope act simply as a separating element between indoor environment and outside environment [54].

As the subcomponents of outside wall; full component that has opaque character and wall cavities that have transparent character, properties of building elements and environmental factors are the influential factors on the thermal performance of outside walls.

Other properties affecting thermal performance are the materials used in outside wall system and different formational and spatial properties of these materials, physical characteristic properties of the materials, thickness and the combination order of materials. Thermal performance is under the influence of external climate elements, air temperature, relative humidity in air, solar radiation, wind and rainfall types [55].

4.4.1. Thermal Insulation Applications in Outside Wall Systems

In any building envelope constructed with classical building materials (normal porosity brick, concrete, wood etc.) heat loss and consequentially fuel consumption is high. Furthermore, spaces that possess such building envelopes are extremely hot during summer season (in sun-facing facades at most). In order to fight against such problems and create spaces which remain hot in winter and cool in summer by heating easily and comfortably with less fuel;

4 different systems are applied in outside walls of Turkish buildings to insulate based on the position of thermal insulation material [56]:

Thermal insulation applications on outside surface of the walls (sheathing)

Thermal insulation applications on indoor surface of the walls

Inter double-wall thermal insulation applications (sandwich wall)

Ventilated outside wall insulation applications (curtain wall system)

The most popular thermal insulation materials in Turkey are fibrous materials and foam materials. Fibrous materials; mineral wools like rockwool and glasswool, foam materials; polystyrene foams and polyurethane foams like (EPS) and (XPS). While selecting insulation materials to apply on outside walls; it is required to select the kind of materials that do not negatively affect the structure of space when interacted with humidity and maintain its insulation property constantly.

4.5. Confirmed Advantages of Concrete Verified by Studying Buildings

Concrete buildings' benefits in terms of energy efficiency:

Concrete is a permanent, reliable and well-known material which is widely used for a number of building types in Europe. The most popular applications in buildings are composed of the materials below:

-Floorings on the ground floor or upper floors.

-Structural cages (for instance; beams, colons and floorings).

-Outside and indoor walls including panels, blocks and decorative elements.

-Roof tiles.

Another reason accounting for the successful use of concrete in building applications is that this material has a wide array of usage areas with respect to structural and material properties. In most of the buildings, heavyweight concrete (high-density concrete) well- known for its physical resistance, fire resistance, noise insulation and gradually-increasing thermal mass is applied.

As a consequence of studies conducted on actual and theoretical concrete buildings it was manifested that concerning the energy performance of buildings, a climatic advantage can be secured in all European states if, in building designs, thermal mass is taken into account. If such effect is calculated pursuant to the measurement principles licensed within the scope of Energy Performance of Building Directive, it can be detected that when a heavyweight building is compared to its lighter counterpart, 2%-15% ratio of advantage is catered in energy consumption. It was also demonstrated in relevant studies that under favorable indoor space conditions, heavyweight buildings are likely to provide, in both hot and cold environmental conditions, finer insulation better than light buildings (on hour basis) for a longer period (on day basis).

In order to exhibit to what extend concrete can, while minimizing energy consumption, meet at the same time the stability of indoor space's climate, a set of tests that utilized theoretical building design was conducted.

A number of computer programs most of which were developed on the basis of EN ISO 13790 standard are utilized in measuring energy use in the buildings. In the study [57], which evaluated concrete and energy performance five programs from Denmark, Germany, and Sweden were practiced. Results of the tests in which the option of five theoretical building design was utilized proved that heavyweight concrete buildings offer important advantages in terms of energy performance once contrasted with their lighter counterparts. All five programs evidently supported the performance advantage of heavyweight building option. When neutral-window positioned heavyweight structures used as houses are compared to their lighter option exhibiting identical properties, it necessitated 2%-9% ratio of less primary and purchased (1.5 to 6 kWh/m /year) energy. When larger quantities of windows are directed to southward, heavier option offers greater advantages [57].

In order to confirm the reality of abovementioned results actual buildings in different climates were analyzed via identical computer programs. Both heavyweight and light- option structural alternatives were taken into account and data pertaining to local-specific climate were included as well. Torre Verde (Green Tower) (Figure 4.1) was built in Portugal, in Lisbon, twelve-story concrete building (7200m) which used residential, built on energy efficient according to calculation. The result of the monitoring, according to the same size conventional building, it was determined that 24 tons less carbon dioxide and the solar thermal system provides %70 for domestic need hot water consumption.

Figure 4.1. Concrete Building in Portugal [57].

It is cast in situ town house in Brussels-Belgium (Figure 4.2).

Figure 4.2.. Concrete Building in Brussels-Belgium [57].

Kvernahuset Youth School in Norway-Fredrikstad. (Figure 4.3) It is provided that energy efficiency and sustainable solutions for the energy which is used precast concrete for energy saving. [57].

Figure 4.3. Concrete Building in Norway-Fredrikstad [57].

The results of this validation study are abridged in Table 4.2 and were extensively in concurrence with the test information gave the five software programs, yet a fascinating perception was made in admiration of intermittent space heating of buildings. There is typically little difference between heavyweight and lightweight structure for buildings when subjected to intermittent heating cycles, however just where the temperature drop between progressive heating cycles is minimized by effecting insulation and sufficient airtightness [57].

Table 4.2. Example From Real Concrete Building Studies [57].

Example from real building studies. Annual energy use (kWh/m²)			
Building Type	Energy Use	Heavyweight	Lightweight
UK/Ireland semi-detached. Average of 9 locations.	Heating **	34	35
Semi-detached. Lisbon	Heating*	17	19
	Cooling	27	32
	Total	44	51
Multifamily, Würzburg	Heating*	51	55
Semi-detached. Stockholm	Heating	78	81
Key * Constant heating regime ** Average of constant and intermittent heating to take account of the common use of intermittent heating in these countries.			

CHAPTER 5

THERMAL PROPERTIES AND NUMERICAL ANALYSIS

In present study, time-dependent thermal behaviors were parametrically analyzed via a software code on opaque wall surfaces with respect to different positioning of structural elements and different direction of the wall, based on individual analysis of heating/cooling loads and total energy consumptions, changes in wall internal surface temperature changes and dissimilar climactic data. Also, in this study 3 different situations were created with respect to the position of insulation materials under different climatic conditions.

5.1. Building Envelope Sections Computed via Numerical Methods

These situations are respectively; uninsulated situation, inner-insulated situation, outer-insulated situation, center-insulated situation. As envelope body element, 20 cm concrete was utilized and XPS (extrude polystyrene foam) was employed as insulation material. As insulation layer, XPS Insulation materials were mounted. This one-piece material followed the values for different Insulation materials for different climates as specified in TS-825 Directive on the Thermal Insulation in Buildings [5]; hence thermal recovery and loss rates under insulation situation were computed.

In Figure 5.1, this section is intentionally not-insulated. The uninsulated exterior wall situation which is respectively 2 cm cement plastering on outside, 20 cm concrete and 2 cm gypsum plastering on inside.

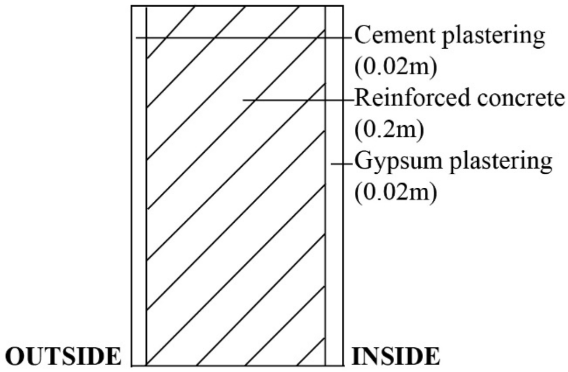


Figure 5.1. Uninsulated Wall.

In Figure 5.2, this section is internal wall insulation option. The interior wall insulation situation in order of 2 cm cement plastering on outside, 20 cm concrete, XPS (Extruded polystyrene) which is increased from 4 cm up to 8 cm based on selected cities (İzmir, İstanbul, Ankara and Erzurum, respectively) data and 0.8 cm gypsum plastering on inside by virtue of insulated material.

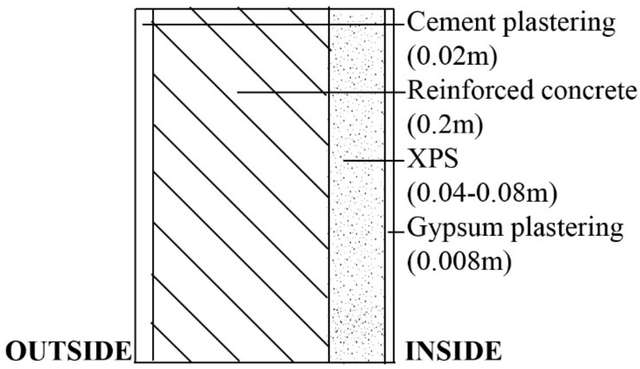


Figure 5.2. Interior Wall Insulation.

In Figure 5.3, this section is external wall insulation option. The exterior wall insulation situation in order of 0.8 cm cement plastering on outside, XPS varies between significantly (4 cm to 8cm), 20 cm concrete and 2 cm gypsum plastering on inside.

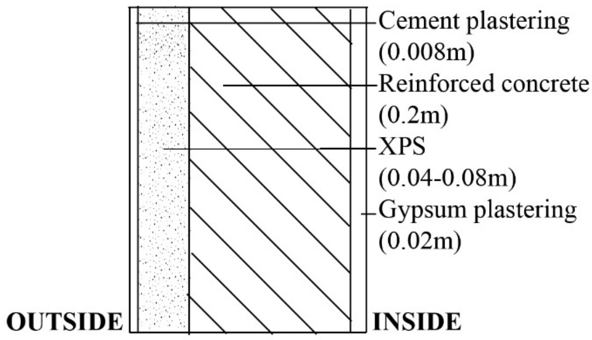


Figure 5.3. Exterior Wall Insulation

In Figure 5.4, this section is sandwich wall insulation. The sandwich wall insulation situation is respectively, 2 cm cement plastering on outside, 10 cm concrete, XPS varies between significantly (4 cm to 8cm), 10 cm concrete and 2 cm gypsum plastering on inside.

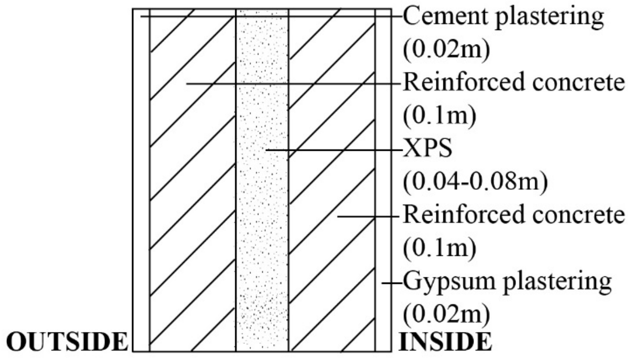


Figure 5.4. Sandwich Wall Insulation.

Thermal Insulation systems has many advantages and disadvantages according to the types of materials and different placement positions [58, 59].

5.1.1. Thermal Insulation Applications on External Surface of the Walls

External façade heat insulation, is an application that protects building's external envelope against the damage of unfavorable atmospheric conditions. In sheathing process, rockwool that is utilized in external facade applications can, with its EPS, XPS insulation plates, significantly minimize heat loss. Sheathing offers cost efficient heating and cooling in buildings during summer and winter season and save up to 50% of energy expenses [58].

Advantages of external insulation system;

-Insulation is continuous and protects the building like a sheath.

-Thermal bridges are minimum.

-All building elements are protected against atmospheric impacts; it also extends building's lifecycle. Bearing elements are protected against corrosion.

-During short term non-operation of the heating system (at nights), indoor environment temperature remains steady.

-It prevents excessive heat during summer season.

-It offers minimum risk of condensation for the water vapor.

-A major part of damages on building physics can be prevented via external heat insulation applications; besides, in the repair of current damages, it proves to be the most effective and durable application of all.

Disadvantages of external insulation system are:

-For the application process a scaffolding should be mounted to the entire façade and the personnel in charge need to be qualified.

-The financial cost is higher [59].

5.1.2. Thermal Insulation Applications on Internal Surface of the Walls

In cases when heat insulation applications on external façade could not be done, heat insulation is applied on indoor surface. When indoor surface was insulated it was observed that heat storage capacity of the walls decreased whereas pre-heating period got shorter [58].

Advantages of internal insulation system are:

-Unlike externally-applied jacketing system, internal insulation system is easier to implement and it is cost effective.

-No harm implemented on outside view of the building.

-No need for scaffold, no vulnerability against outside air conditions during application hence offering ease of application.

-Conditioning of indoor environment can be speeded up.

Disadvantages of indoor insulation system:

-In the connection points of floorings and indoor walls, thermal bridges are formed which decrease insulation efficiency.

-Ground water or surface (rain, snow) water that leaks into the wall (bearing element) due to micro-cracks and similar damages having occurred on the brittle-natured support and filler structure materials due to thermal expansions, dirty atmosphere, different ground subsidence and similar occurrences which in effect leads to an increase in wetting and corrosion. As a result, the water reaches indoor surface and either causes fungus or mold formation or due to wetting, the paint may fall and similar damages may occur [59].

5.1.3. Sandwich Wall Thermal Insulation Applications

This system also known as sandwich wall, sandwich insulation or sandwich system, is formed by applying insulation materials between the layers. As regards this insulation application, huge differences exist between Turkey and other European states.

Advantages of sandwich wall system are;

-XPS plates, in the course of time, do not disappear or lose shape and perform as a thermal insulator during the entire lifecycle of building.

-Plates are not damaged due to the freezing and solutions occurring on the external surface of building.

Disadvantages of sandwich wall are;

-Condensation is likely to occur between outside wall and thermal insulation layer.

-It increases the financial cost.

-All concrete elements and indoor wall must be aligned, which is difficult to achieve in practice [59].

5.2. Thermophysical Properties and Thermal Transmittance Calculation of the Wall Models based on Different Climatic Data

In present study a parametric research has been conducted. Based on different materials, geometry and properties as well as different climate conditions the problem of one-dimensional period dependent heat transfer was investigated. Thermophysical properties of the materials required for this study are as given in (Table 5.1) [14].

Table 5.1. Thermophysical Properties of the Used Material for Formed in the Wall Composition. [14]

Material name	Thickness (m)	Conductivity (W/m-K)	Specific Heat (J/kg-K)	Density (kg/m^3)
Outside gypsum plastering	0.008 and 0.02	0.7200	840	1860
Insulation material XPS	0.03-0.08	0.035	1400	35
Reinforced concrete	0.1 and 0.2	2.3000	1000	2300
Inside gypsum plastering	0.008 and 0.02	0.3800	1090	1120
Total	0.268-0.308			

For the building envelope thermal insulation specifically calculations are based on TS-825 [5] for 4 climatic zones overall heat transfer coefficient values are given in Table 5.2, at the first column which is recommended values in TS-825 [5]. By using these values, XPS thermal insulation thickness was calculated for each situation individually. These values are based approach to determine required different insulation thicknesses are obtained different wall types by using Equation 5.1.

$$U = \left[\frac{1}{h_i} + \sum_{i=1}^{N} \frac{L_i}{k_i} + \frac{L_{ins}}{k_{ins}} + \frac{1}{h_o}\right]^{-1} \tag{5.1}$$

where, U is overall thermal transmittance in W/m^2K. Where, L_i, k_i, h_o, h_i, the material's thickness, its thermal conductivity h_i and h_o are inside and outside surface heat transfer coefficient in W/m^2K. These values are taken 25 and 7 W/m^2K are defined in TS-825 [5]

Table 5.2. Thermal Insulation Specifically Measurements are Based On TS-825. [5]

	TS-825 U-Value (W/m-K)	Exterior Wall Insulation Width(m)	Interior Wall Insulation Width(m)	Sandwich Wall Insulation Width(m)
ANKARA	0.50	0.059	0.0595	0.0584
ERZURUM	0.40	0.0765	0.077	0.0759
İSTANBUL	0.60	0.0473	0.0478	0.0467
İZMİR	0.70	0.039	0.0395	0.0384

Calculated Insulation thickness values given in Table 5 were defined again based on manufacturer values, and new overall heat transfer coefficient values are determined and given in Table 5.3. Uninsulated wall U value is calculated by using Equation 1 and used as 3.187 W/m-K.

Table 5.3. The Thickness of the Applied Insulation Materials and the New U Values.

	XPS Width(m)	Exterior Wall Insulation U-Value (W/m-K)	Interior Wall Insulation U-Value (W/m-K)	Sandwich Wall Insulation U-Value (W/m-K)
ANKARA	0.06	0.49309	0.49674	0.48907
ERZURUM	0.08	0.38469	0.38691	0.38224
İSTANBUL	0.05	0.57394	0.57890	0.56851
İZMİR	0.04	0.68653	0.69363	0.67876

5.3. Building Typologies and Properties

The European Energy Performance of Building Directive (EPBD)-(2002/91/EC) [60] promulgated by European Parliament in 2003 is aimed at efficient energy use in current and projected buildings. It also specified using energy more effectively in buildings by enforcing a set of standards and codes. Agreeing upon a collective methodology in measuring total energy performance of buildings is the most substantial tool. What is specifically underlined with the word *building* here is; a top-covered structure surrounded with walls on four sides in which energy is used to regulate the climate of indoor space. 'Building energy performance' is; the amount of energy that is physically consumed or projected to be consumed to meet a number of needs caused by the standard usage of buildings including but not limited to the services such as heating, cooling, ventilation and lighting. The amount of energy depends on applied material, climate properties, position, solar effect, environmental conditions in addition to usage conditions which collectively affect energy demand.

This methodology entailing energy-performance measurement standards for buildings integrates 2009/28/EC Directive. As put forth in this method, buildings should be classified pursuant to this Directive in question [60].

-single-family houses of different types;

- Apartment blocks;
- Offices;
- Educational buildings;
- Hospitals;
- Hotels and restaurants;
- Sports facilities;
- Wholesale and retail trade services buildings;
- Other types of energy-consuming buildings.

For sampling purposes of this thesis, 24 Hours 7 days cooling and heating buildings were selected to exemplify residences like single-family houses and apartment blocks and hospitals with respect to their ultimate function. Computation of heating and cooling loads of buildings lays the foundation for the analysis conducted with respect to ASHRAE's Thermal Comfort Standard 55 [14], thermal environmental conditions for human occupancy describes the combinations of acceptable indoor space conditions and

Table 5.4 shows operative temperature range for building occupants in typical winter and summer conditions. Detailed temperature values for different buildings are given in Appendix A.

Table 5.4. ASHRAE Guideline Interior Air Temperature [14].

Type of Space	°C	
	Winter	Summer
Residences, apartments, hotel and motel guest rooms, convalescent homes, offices, conference rooms, classrooms, courtrooms and hospital patient rooms.	20-22	23-26

In this study inside air temperature values are assumed as 20°C for winter condition also for this condition January data were used, and 24°C for summer period July meteorological data were used.

5.4. Psychrometric Chart

"The psychrometric chart is a convenient and useful tool for determining moist air psychrometric properties, and visualizing the changes of properties in a sequence of psychrometric processes; e.g., as the outside and return air mixes, proceeds through heating and cooling coils, the supply fan, supply duct, and on to the conditioned space [61]."

Psychrometric diagram is the graphical expression of the thermodynamic properties of humid air. It was prepared to provide maximum compatibility in solving engineering- project problems. Psychrometric diagram is also known as h-x diagram. Air without any saturated properties can, with these properties, create unsaturated conditions in a sense. If relative humidity (ϕ) exceeds 100%, dewing phenomenon occurs. By using psychrometric diagram, it becomes easier to express the properties of humid air under different air conditions. In the event that even only two independent properties of air are known it still becomes possible to collect data on all the other properties of air [62].

Psychrometric diagram provides data on thermodynamic properties of humid air under specific atmosphere pressure; some of these properties are dry thermometer temperature, wet thermometer temperature, dew point temperature, specific humidity, relative humidity, specific volume and enthalpy [62].

In this thesis, comfort zone values in the graphics below were based on ASHRAE Standard 55 Thermal Environmental Conditions for Human Occupancy 2010 [14].

Psychrometric chart was prepared according to January and July data for the cities of Ankara, Erzurum, İstanbul and İzmir [6]. Highlighted area indicates comfort zone. January and July data of İzmir are in Figures 5.5 and 5.6 analyzed temperature data belong to the period between 2005-2014, and 24 –hour mean values of the measurements are such given;

-Ankara July data were identified as +24.9°C and Ankara January data were identified as +1.18 °C.

-Erzurum July data were identified as +19.3°C and Erzurum January data were identified as -10.7°C.

-İstanbul July data were identified as +24.1 °C and İstanbul January data were identified as +6.15 °C.

-İzmir July data were identified as +28.8 °C and İzmir January data were identified as +9.3 °C.

Psychrometric charts for the other cities, namely Ankara, Erzurum and İstanbul are given in Appendix B Figures B1-B6, respectively.

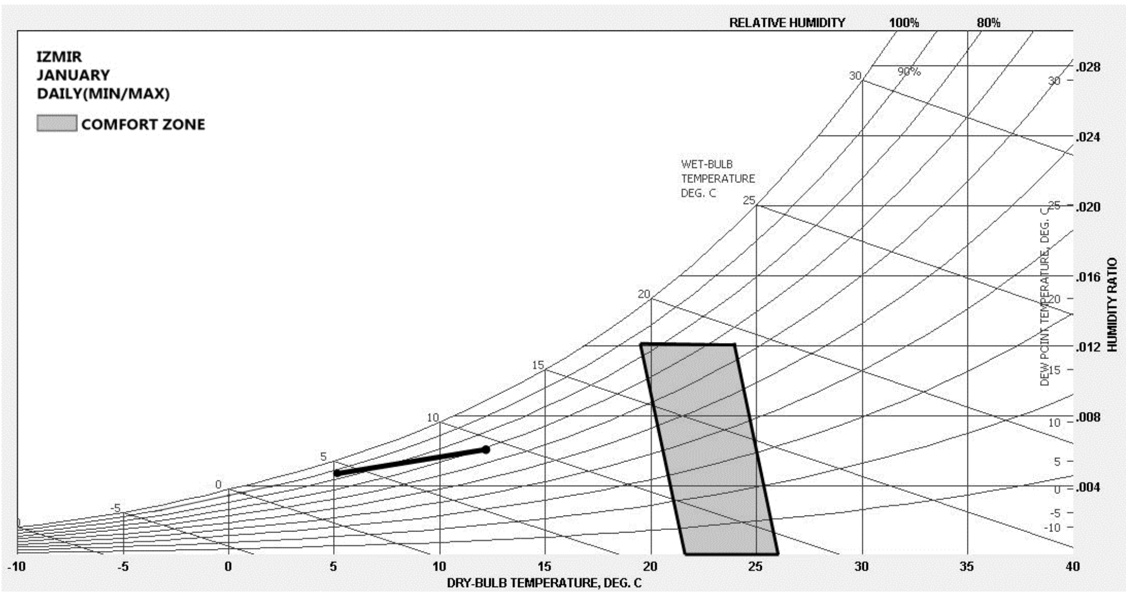


Figure 5.5. Climate and Comfort Zones January in İzmir.

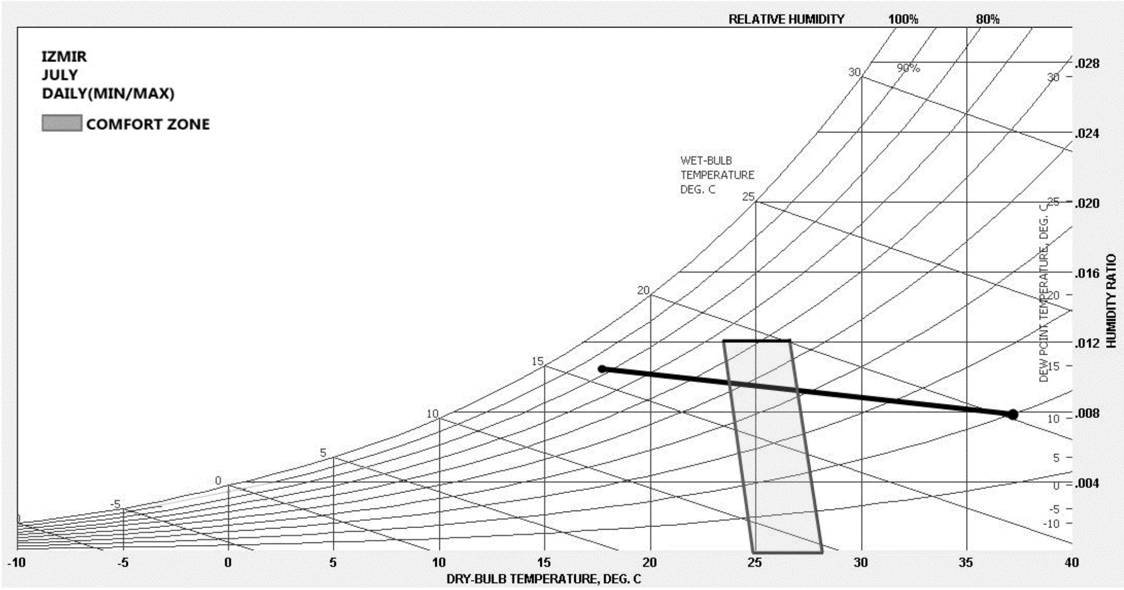


Figure 5.6. Climate and Comfort Zones July in İzmir.

5.5. Programming Language and Visual Basic

Object-oriented designs have lately gained popularity in programming languages and a huge number of languages also created versions which can present object-oriented programming. Object-oriented programming is one of the latest stages in programming languages. It allows the programmer to create his/her own classification & object and perform operations on the system. Upon utilizing OOP and developing Visual programming, a rise has been witnessed in beautifully-visualized and practical software programs. These programs received increased popularity and motivated further researchers to conduct studies in relevant field.

Each programming language may have different usage objectives and directions. In the light of previous researches, it was resolved to employ Visual Basic Software as the programming language compatible with modern technology in this thesis.

Microsoft Visual Basic is a software compiler developed by Microsoft. Utilized specifically in Windows environment as a tool to develop programming, Visual Basic has different features compared with other classical programming languages and it is a programming language with wider usage webs [63].

To use as the source of data for the model developed on Visual Basic program and the code created alongside, a measurement has been conducted within the context of data on temperature, solar and wind figures collected from Turkish Ministry of

Forestry and Water Affairs General Directorate of Meteorology located in cities of Ankara, Erzurum, İstanbul, and İzmir.

5.6. One-Dimensional Problem for Opaque Wall

An opaque wall model was created where the heat conduction equation was solved using an implicit finite difference method. The insulation position was changed and for each location energy demand might has been computed. "In transient problems, however, the temperatures change with time as well as position, and thus the finite difference solution of transient problems requires discretization in time in addition to discretization in space. This is done by selecting a suitable time step Δt and solving for the unknown nodal temperatures repeatedly for each Δt until the solution at the desired time is obtained [30]." The transient and no heat generation one dimensional heat conduction equation in a multilayered wall thickness L parallel isotropic and homogeneous layer.

$$\rho c_p \frac{\partial T(t,x)}{\partial t} = k \frac{\partial^2 T(t,x)}{\partial x^2} \tag{5.2}$$

where: t and x represent the time and special coordinates, T is the temperature k, ρ and c_p are the thermal conductivity, density and specific heat, respectively.

The surface boundary and the initial conditions taking into consideration the climatic conditions and surface properties and is calculated using the formula given in Equation 5.2.1 and 5.2.2.

at $x = 0$,

$$-k_0 \frac{\partial T}{\partial x} \rvert_{x=0} = \alpha I + \sigma\varepsilon\left(T_{sky}^4 - T_{s,0}^4\right) + h_o\left(T_{\infty,o} - T_{s,0}\right) \tag{5.2.1}$$

at $x = L$,

$$-k_L \frac{\partial T}{\partial x} \rvert_{x=L} = h_i\left(T_{s,L} - T_{\infty,i}\right) \tag{5.2.2}$$

at $t = 0$,

$$T\,(x,0) = T_{initial} \tag{5.2.3}$$

where k_0 is the thermal conductivity of the material of the outside surface which is plaster. k_o is taken as 0.72 W/m-K.

α is absorption coefficient of the outside surface radiation property and it is assumed to be 0.4.

I represents solar radiation value and it is defined by using reference numbered 7 for different regions of Turkey and different direction. Figure 5.7 and Figure 5.8 are showed İzmir solar radiation distribution for monthly average of the daily values use with January and July climatic data respectively. And the other cities, namely Ankara, Erzurum and İstanbul are given in Appendix C, Figure C1 to C6 respectively.

The solar radiation database is developed using the Photovoltaic Geographical Information System - Interactive Maps [7]. In this interactive maps data for the European subcontinent was developed using the solar radiation model called r.sun [64] and dedicated programs integrated into the GIS software GRASS [65]. The r.sun algorithms are based on equations published in the European Solar Radiation Atlas [66].

The essential database represents the period 1981–1990 and it contains 12 monthly averages of the daily global irradiation climatic parameter. This parameter contains in itself; average daily solar irradiance with any orientation and inclination angles.

Figure 5.7 shows, global irradiance on a fixed vertical plane (W/m^2) according to the orientation (East, South, West and North) in January. Figure 5.8 demonstrates to July the distribution of daily solar radiation data in İzmir. The sub-figures for west- and east-facing are asymmetric in time and slope inclination angle and are mirror images. Low-angle north-facing slopes are in sunlight for only a short period in winter time but mainly diffuse solar radiation affect. For south-facing slopes, peak occurs on in January and winter time of the year. However in summer time east facing slopes and west facing slopes peak in İzmir also other selected cities are the same. For south facades in January, receive the most direct sunlight over the course of a day by comparison with in summer time. Y-axis demonstrates global irradiance value (W/m^2) and the X-axis represents 2 minutes hourly time step of a day.

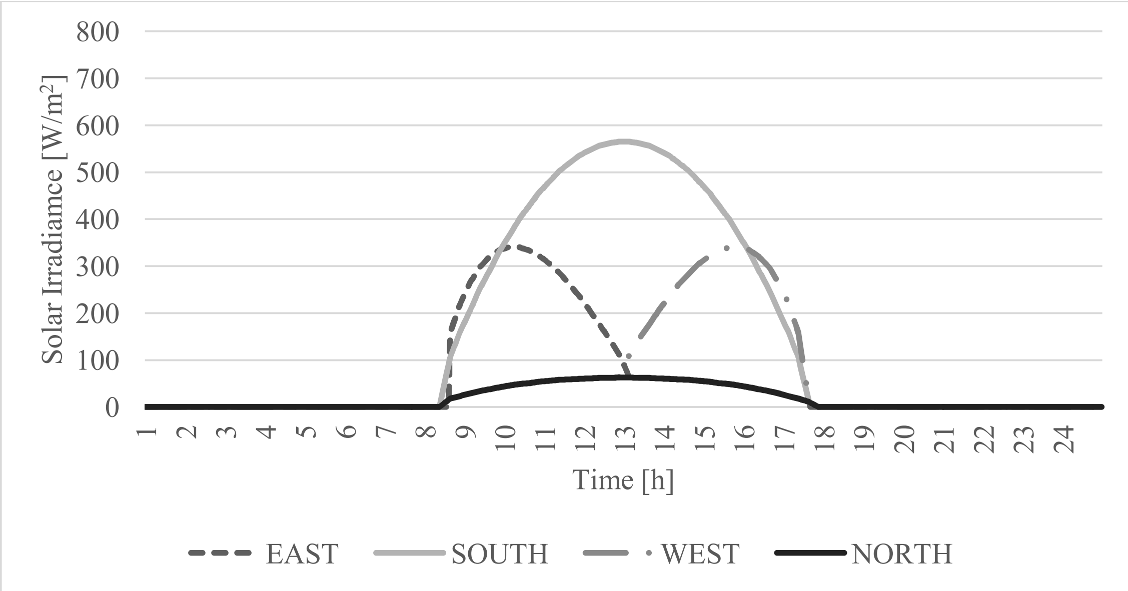


Figure 5.7. Monthly Average of the Daily Solar Radiation at January for İzmir

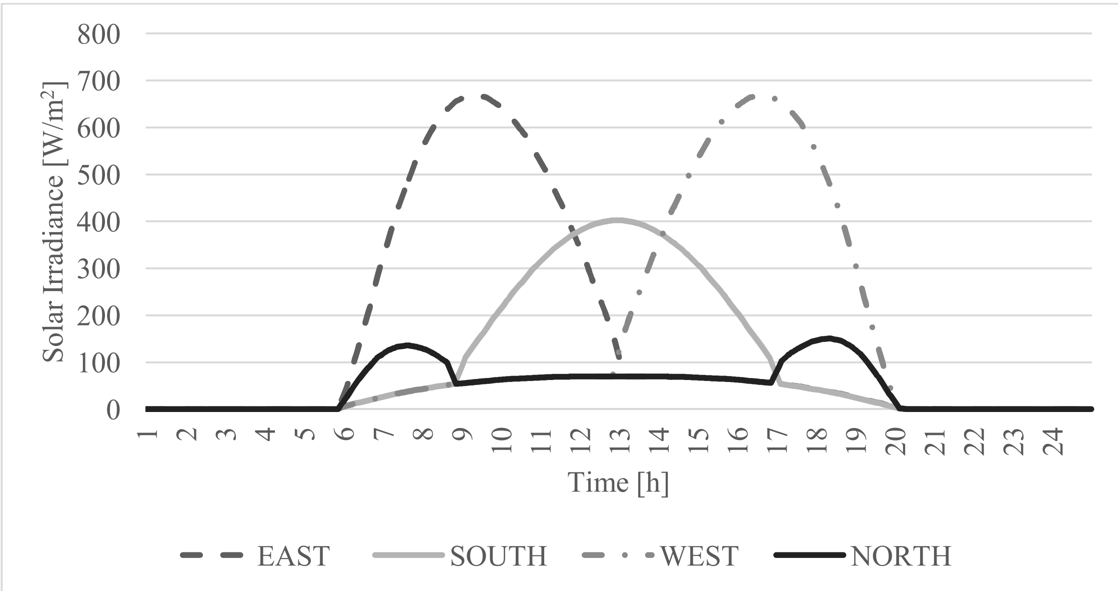


Figure 5.8. Monthly Average of the Daily Solar Radiation at July for İzmir

σ and ε represent the Stefan-Boltzmann constant which is taken as; 5, 67× 10^{-8}W/ m^2K^4 and the emissivity of the emitting surface which is assumed as; 0.93, respectively.

$T_{s,0}$ $T_{s,i}$ are the outside and inside surface temperature which was calculated by numerically in the code. $T_{\infty,i}$ represents inside air temperature is assumed as 20°C and 24°C for winter time and summer time in order of January and July data. And $T_{\infty,0}$ exemplifies that outside air temperature of monthly average of the daily data. Meteorological data were used as an outside boundary conditions for different cities in

Turkey. These were selected for lowest and highest average temperatures months which were January and July respectively. Hence, outdoor air temperature distributions were given in Figure 5.9 for İzmir by using meteorological data over the years 2005-2014. And the other selected cities are given in Appendix D, Figure D1 to D3, respectively.

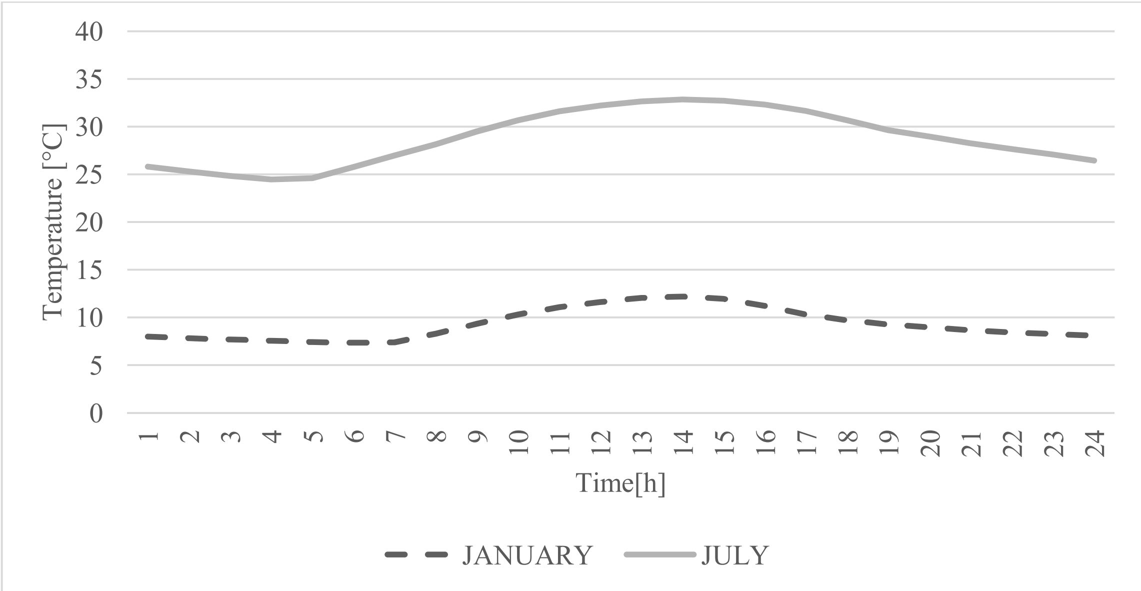


Figure 5.9. Monthly Average of the Daily Meteorological Data at January and July for İzmir.

T_{sky} is the effective sky temperature calculated by using Equations 5.3;

$$T_{sky} = T_{\infty} (0.8 + \frac{T_{dp}}{250})^{0.25} \tag{5.3}$$

Tsky are variable based on climatic conditions depending on time. The default calculation for sky temperature based on dew point temperature and outside air temperature is obtained [67]. T_{dp} is dew point temperature. The dew point is associated with relative humidity and air temperature and the dew point temperature is in units of degrees Celsius. And the results were given graphically in Figure 5.10 and Figure 5.11 illustrates the variation of the effective sky temperature, using the estimated air temperature and relative humidity in different climatic conditions. The values are generated using with İzmir's January and July weather data and Equation 3. When the relative humidity increases, the effective sky temperature increase. However, the air temperature increases, relative humidity decreases. (Figure 16, Figure 17). And the other cities, namely Ankara, Erzurum and İstanbul are given in Appendix E, Figure E1 to E3, respectively.

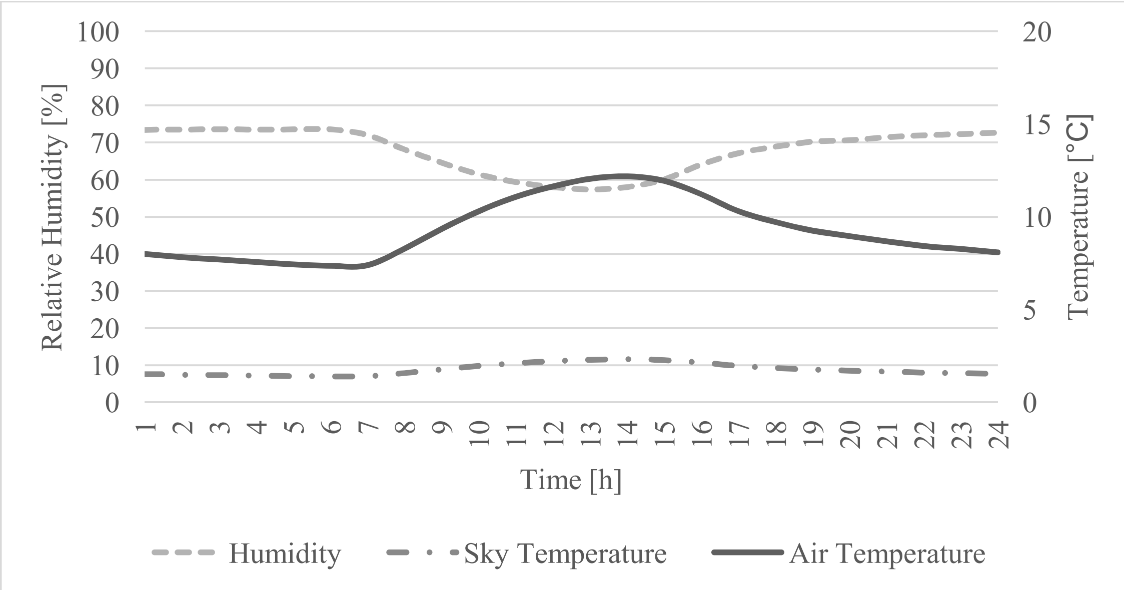


Figure 5.10. Sky Temperature and Air Temperatures and Relative Humidity Versus Time of the Monthly Average of the Daily January Data in İzmir.

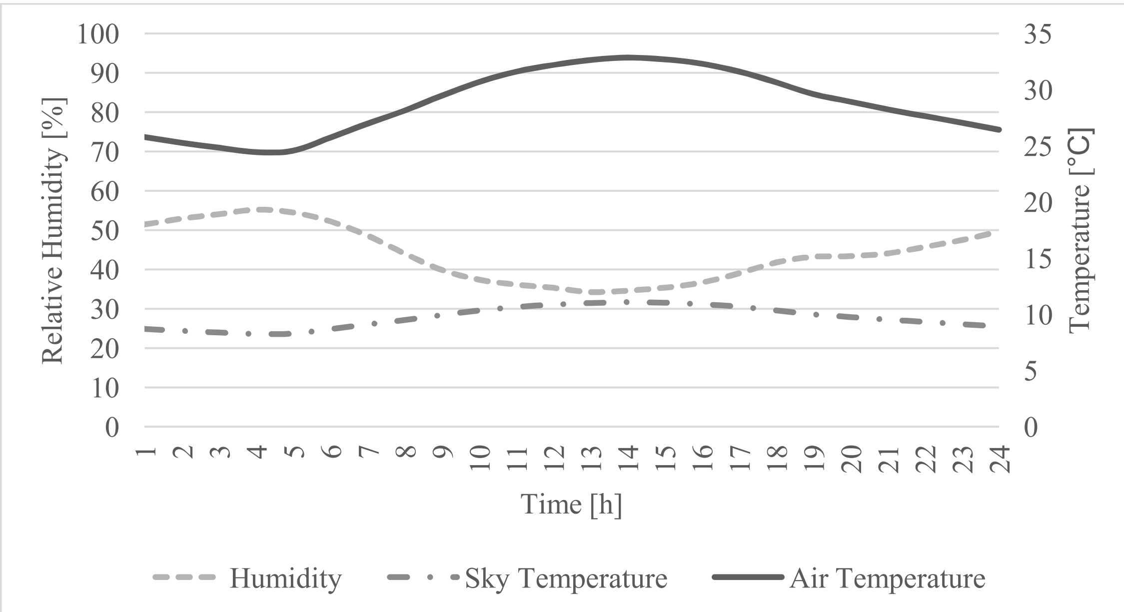


Figure 5.11. Sky Temperature and Air Temperature and Relative Humidity Versus Time of the Monthly Average of the Daily July Data in İzmir.

h_0 and h_i represent convection heat transfer coefficient in W/ m^{2}K. h_0 is taken 25 W/ m^2°C and h_i is taken 7.6923 W/ m^{2}K in the calculations.

$T_{\infty,o}$ and $T_{\infty,i}$ are the outside and inside temperatures of the fluids sufficiently far from the surface. The opaque wall section with the boundary conditions is shown in Figure 5.12. However, the fluid temperature equals the surface temperature of the wall.

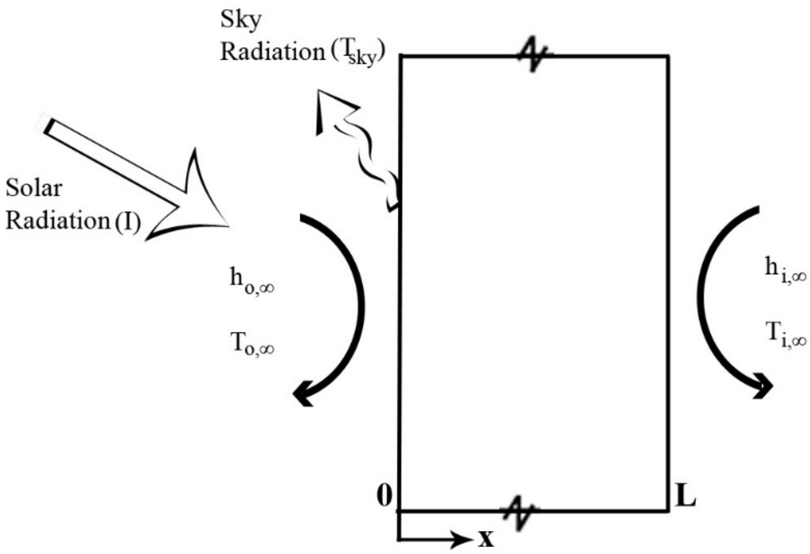


Figure 5.12. Heat Flow Through a Wall is One Dimensional When the Temperature of the Wall Varies in One Direction Only.

$T_{initial}$ is the initial temperature and it is assumed that all meshes firstly defined. After first running, the new temperature distribution is defined as a new initial temperature distribution.

5.7. Numerical Analysis of the Problem

The finite difference representations of the partial derivative terms of the one dimensional time dependent heat conduction equation defined in Equation 5.2 can be written as by using implicit method.

$$\frac{\partial T}{\partial t} = \frac{T_j^{i+1} - T_j^i}{\Delta t} \tag{5.4}$$

$$\frac{\partial^2 T}{\partial x^2} = \frac{T_{j+1}^{i+1} - 2T_j^{i+1} + T_{j-1}^{i+1}}{(\Delta x)^2} \tag{5.5}$$

Where T_j^i and T_j^{i+1} are the temperatures of node i at times $t_i = i\Delta t$ and, $t_{i+1} = (i+1)\Delta t$ respectively, and $T_j^{i+1} - T_j^i$ represents the temperature change of the node (Figure 5.13) during the time interval Δt between the time step i and *i+1*. Equation 5.2 can be written Equation 5.4 and 5.5.

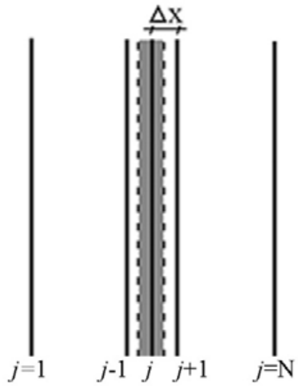


Figure 5.13. The Nodal Points for One-Dimensional Conduction in a Plane Wall.

$$\frac{T_{j+1}^{i+1} - 2T_j^{i+1} + T_{j-1}^{i+1}}{\Delta x^2} = \frac{1}{\propto} \times \frac{T_j^{i+1} - T_j^i}{\Delta t} \tag{5.6}$$

where; $\propto = k/\rho c_p$ and Equation 5.6 can be arranged as;

$$-\frac{1}{\Delta x^2} T_{j-1}^{i+1} + \left(\frac{2}{\Delta x^2} + \frac{1}{\propto \Delta t}\right) T_j^{i+1} - \frac{1}{\Delta x^2} T_{j+1}^{i+1} = \frac{1}{\propto \Delta t} T_j^i \tag{5.7}$$

For solving unknown temperatures seen in Equation 5.7 which is composed a tridiagonal matrix system, the Equation 5.8 can be written as;

$$b_j T_{j-1}^{i+1} + d_j T_j^{i+1} + a_j T_{j+1}^{i+1} = c_i \tag{5.8}$$

where;

$$b_j = +\frac{1}{\Delta x^2}, \tag{5.8.1}$$

$$d_j = -\left(\frac{2}{\Delta x^2} + \frac{1}{\propto \Delta t}\right), \tag{5.8.2}$$

$$a_j = +\frac{1}{\Delta x^2}, \tag{5.8.3}$$

$$c_j = -\frac{1}{\propto \Delta t} T_j^i \tag{5.8.4}$$

The arrangement of equations can be give a role as a matrix equation where the unknowns are the values T_j in the interior points of the solution domain. The implicit solution is implemented in Thomas Tridiagonal Matrix Algorithm (TDMA) shown in Figure 5.14 is simplified form of Gaussian elimination that can be used to solve tridiagonal system of equations from direct finite difference methods. This method uses diagonal matrices, since a large number of elements of the matrix of coefficients for the system of equations are zero [68].

$$\begin{bmatrix} d_1 & a_1 & 0 & 0 & 0 & \dots & & & \dots & 0 & 0 & 0 \\ b_2 & d_2 & a_2 & 0 & 0 & 0 & \dots & & & & 0 & 0 \\ 0 & b_3 & d_3 & a_3 & 0 & 0 & 0 & \dots & & & & 0 \\ \vdots & & & & & & \vdots & & & & & \vdots \\ 0 & 0 & 0 & 0 & 0 & b_j & d_j & a_j & 0 & 0 & 0 & 0 \\ \vdots & & & & & & \vdots & & & 0 & 0 & 0 \\ 0 & \dots & & & & & & & & & 0 & 0 \\ 0 & 0 & \dots & & & & & & & b_{n-1} & d_{n-1} & a_{n-1} \\ 0 & 0 & 0 & \dots & & & & & & \dots & b_n & d_n \end{bmatrix} \begin{vmatrix} T_1 \\ T_2 \\ T_3 \\ T_4 \\ \vdots \\ T_j \\ \vdots \\ T \\ T_{n-1} \\ T_n \end{vmatrix}^{i+1} = \begin{vmatrix} C_1 \\ C_2 \\ C_3 \\ C_4 \\ \vdots \\ C_j \\ \vdots \\ C \\ C_{n-1} \\ C_n \end{vmatrix}^{i}$$

Figure 5.14. Thomas Tridiagonal Matrix Algorithm.

The tridiagonal matrix system with a three-line bandwidth can be solved and the unknowns temperature values $T_1^{i+1}, T_2^{i+1}, \dots, T_n^{i+1}$ can be found by using Equation 5.9.1 and 5.9.2, firstly for determining the new d_i and c_i values as;

$$d_j = d_j - \frac{b_j}{d_{j-1}} \times a_{j-1} \qquad j = 2,3, \dots n \tag{5.9.1}$$

$$c_j = c_j - \frac{b_j}{d_{j-1}} \times c_{j-1} \qquad j = 2,3, \dots n \tag{5.9.2}$$

The unknown temperature values are computed from back substitution according to the Equation 5.10.1 *a* and 5.10.2;

$$T_n = \frac{c_n}{d_n} \tag{5.10.1}$$

$$T_j = \frac{c_j - a_j \times T_{j+1}}{d_j}, \qquad i = n-1, n-2, \ldots, 2, 1 \tag{5.10.2}$$

This direct method was defined by using modified Gaussian elimination procedure, and solved this kind of physical problems reduced by a tridiagonal matrix system.

Transient one dimensional heat conduction problem defined in Equation 5.2 can be solved by the TDMA by using described boundary and initial conditions for the plane wall.

5.7.1. Interface Boundary Condition

Opaque building wall is composite material having different kind of layers. So intersection of the layers must be defined because of having different specific parameters. "Transient one-dimensional heat conduction in a plane wall of thickness *L* constant conductivity *k* with a mesh size of $\Delta x = L/M$ and nodes 0, 1, 2. . . *M* in the x-direction, as shown in Figure 5.15. Noting that the volume element of a general interior node *m* involves heat conduction from two sides and the volume of the element is $V_{element} = A\Delta x$, the transient finite difference formulation for an interior node as [30];"

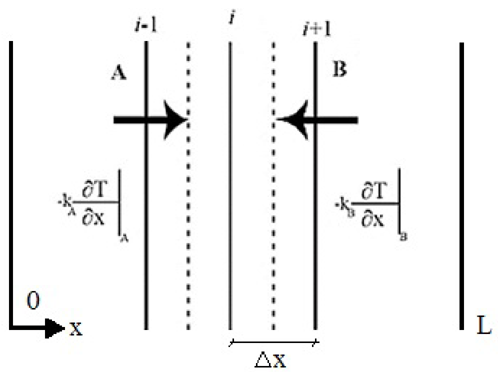


Figure 5.15. The Nodal Points and Volume Elements for the Finite Difference Formulation of One-Dimensional Conduction in a Plane Wall.

When the wall covers layers having different thermophysical properties, energy balance can be written at the interface as;

$$k_A \frac{T_{j-1}^{i+1} - T_j^{i+1}}{\Delta x} + k_B \frac{T_{j+1}^{i+1} - T_j^{i+1}}{\Delta x} = 0 \tag{5.11}$$

Equation 5.11 can be arranged as;

$$T_{j-1}^{i+1} + T_j^{i+1} - \frac{k_B}{k_A}\left(T_{j+1}^{i+1} - T_j^{i+1}\right) = 0$$

$$-T_{j-1}^{i+1} + \left(1 + \frac{k_B}{k_A}\right)T_j^{i+1} - \frac{k_B}{k_A}T_{j+1}^{i+1} = 0 \tag{5.12}$$

where;

$$b_j = 1\,, \tag{5.12.1}$$

$$d_j = -\left(1 + \frac{k_B}{k_A}\right) \tag{5.12.2}$$

$$a_j = \frac{k_B}{k_A} \tag{5.12.3}$$

$$c_j = 0 \tag{5.12.4}$$

These results were used at the TDMA for each interface described in the conduction problem separately. The numerical problem algorithm is given in Figure 5.16.

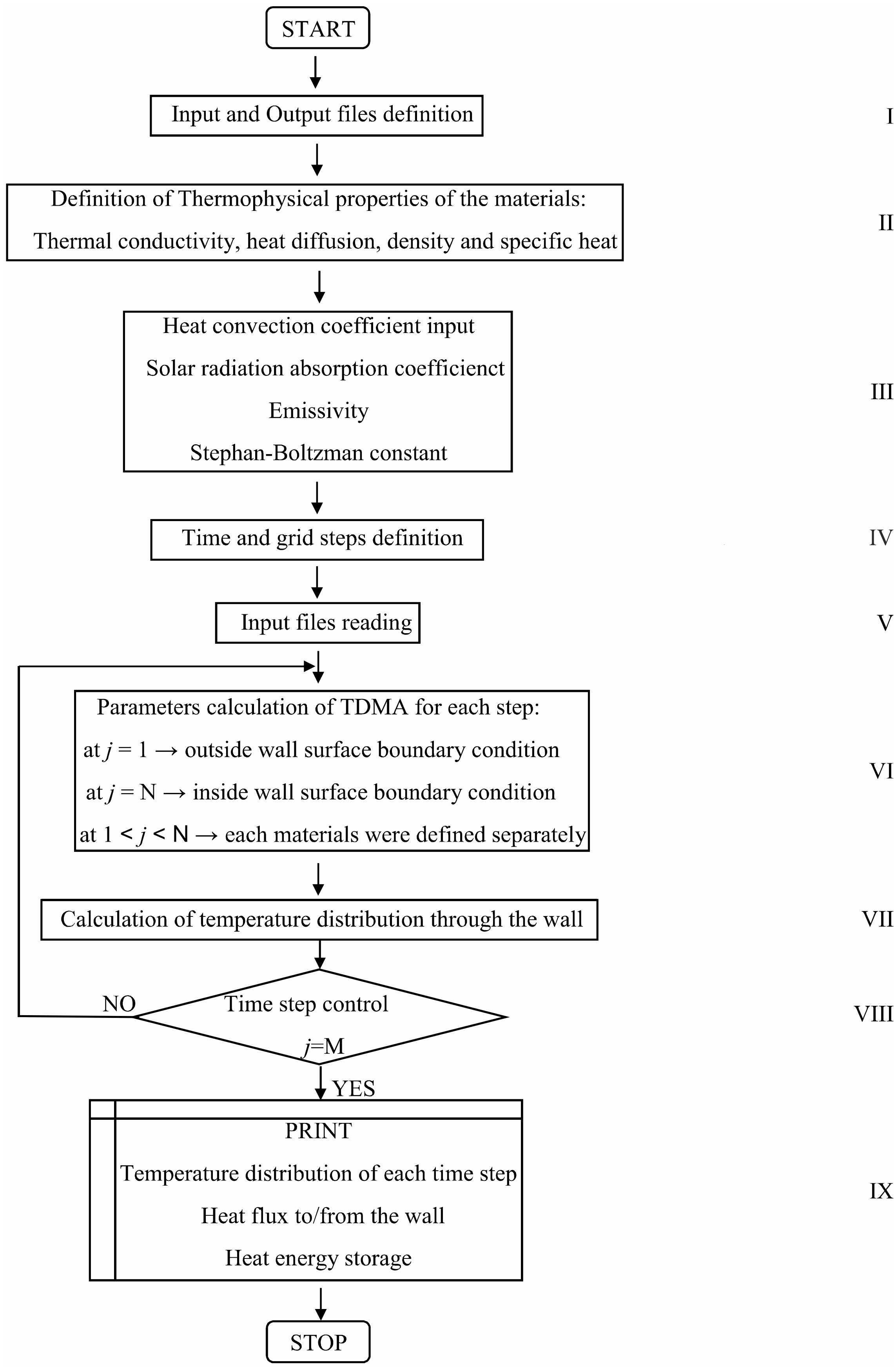


Figure 5.16. Design of Visual Basic Flowchart

Figure 5.16 shows the flowchart of numerical evaluation of a model for transient, one dimensional heat conduction to visual basic programming. This is a standard root-finding problem in VB program. To evaluate the implicit finite difference equation a large number of roots must be available. First input and output items based on climatic data and inside condition data are defined in code (in Figure 5.16 numbered I). After data input and output for temperature distribution and heat transfer values operations, each wall materials' thermophysical properties are given in second step (II). These are ρ (density), c_p (specific heat), k (thermal conductivity), $\propto$ (heat diffusivity) is defined $k/\rho c_p$. In next step, α, σ and ε are given. And these values are (III);

Absorption coefficient; α = 0.4,

Stefan-Boltzmann constant which is taken as; σ = 5, 67× 10^{-8}W/ m^2K^4 and,

Emissivity of the emitting surface which is assumed as; ε = 0.93.

Once you have entered the values, time and grid steps are determined (IV). Grids are generated that according to different wall models. These identifications are;

Grid line spacing are associated is 0.001 m.

Time step help within a while loop so, time step size is assumed that 2 minutes for one day has 720 steps.

Solving the problem, FOR.. NEXT loops are identified with input files (V). And a simple loop has gone around the loop, each time loop variable is changed. On this structure allows to repeat the statements in a loop until the condition is True or until it becomes True, a specified number of times, or once for each data in a calculation in numbered VI and VIII. Before the statement loops again, the temperature distribution through the wall is calculated in numbered VII.

In consequences of these following iteration steps over and over again temperature distribution through the wall, heat energy storage and heat flux values to/from the inside and outside surfaces are printed in number IX.

5.8. Limitations

This section presents all necessary steps and calculations in order to demonstrate that the reactions have been conducted from heat transfer limitations. These limitations of the current study are;

- On opaque wall surfaces with respect to different positioning of structural elements are identified 20 cm concrete, XPS (extrude polystyrene foam) insulation material thickness are differed with climatic condition varies between 4 cm and 8 cm and also specified in TS-825 Directive on the Thermal Insulation in Buildings. Outside and inside plasters thickness are 0.8 cm or 2 cm according to wall compositions.
- Based on different materials, geometry and properties as well as different climate conditions the thermophysical properties of the materials required for this study is used the values in the referenced 14. Also thermophysical properties are assumed to be constant based on average temperature.
- Inside and outside environment temperature is assumed as 20°C and 24°C for winter time and summer time in order of January and July data. For outside boundary condition Meteorological data were used for different cities of Turkey, namely Ankara, Erzurum, İstanbul and İzmir. These were selected for lowest and highest average temperatures months which were January and July respectively.
- Outside temperature and humidity values were taken from the Turkish Ministry of Forestry and Water Affairs General Directorate of Meteorology [6] data based on (2005-2014) year average values and solar energy data which collected from Photovoltaic Power Systems Programme [7] (PVPS) of the International Energy Agency (IEA) data based on 1981–1990 years average values.
- View Factor of the surface to the sky is assumed to be unit for the sky radiation calculation in Equation 5.2.
- Heat convection values for inside and outside surfaces were defined as constant for summer and winter conditions.
- Daily average climate data for January and July were calculated by using monthly data for each situation.
- Time step and grid size are considered 2 minutes for one day has 720 steps and 1 mm, respectively.
- It has not taken into account the internal gain of the indoor, only for the assessment of the thermal behavior of the wall is considered.
- Specifically intersection points of two building materials, the corresponding energy storage for tangential displacements is neglected.
- The rate of decay or the growth of an error in the loop is dependent on the growth factor to the power of the number of time steps after the error was introduced.

However, the current study especially for 1-D time dependent heat conduction problem is solved use with implicit discretization. So it can be shown that the explicit scheme is stable if and only if Fourier number smaller than 0.5 called conditionally stable. The implicit scheme is stable for any values of Fourier number, called unconditionally stable.

CHAPTER 6

RESULTS AND DISCUSSIONS

This chapter mainly includes the results of the time-dependent thermal behaviors were parametrically analyzed via a software code on opaque wall surfaces with respect to different positioning of structural elements and different methods of use, based on individual analysis of heating/cooling loads and total energy consumptions, changes in wall internal surface temperature changes and dissimilar climactic data.

One-dimensional time-dependent heat transfer equation was solved via implicit finite difference method on the external surface of envelope with Visual Basic program, exposed to external environment temperature and for multi-layered walls which, in their internal surface too, in contact with internal environment temperatures that are in constant temperature or instable temperature depending on their functions. A dynamic system that appraise the situation of the thermal inertia of the wall structure which utilized for determination of heating and cooling loads transmission.

On the basis of Visual Basic program to reach the correct results for temperature and heat flow, For…Next loop is used [68]. The For…Next construction performs the loop a set number of times. On this structure allows to repeat the statements in a loop until the condition is True or until it becomes True, a specified number of times, or once for each data in a calculation. (Figure 6.1)

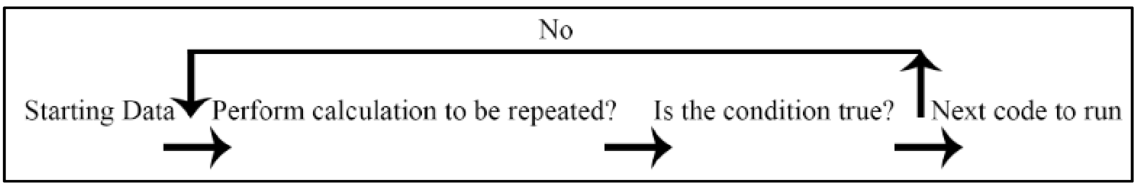


Figure 6.1. Loop Structure

By using repeated results, it is possible to achieve more accurate results. So, in this problem it is specified the initial temperature and then it is changed from one repetition to the next. Until it becomes converging the number. The number variable starts at 10°C for winter season at each point of the section of the wall at 24°C for summer season in İzmir and is changed with regard to calculation method and formulas, ending after the value of number reaches to fall into repetition. (Figure 6.2)

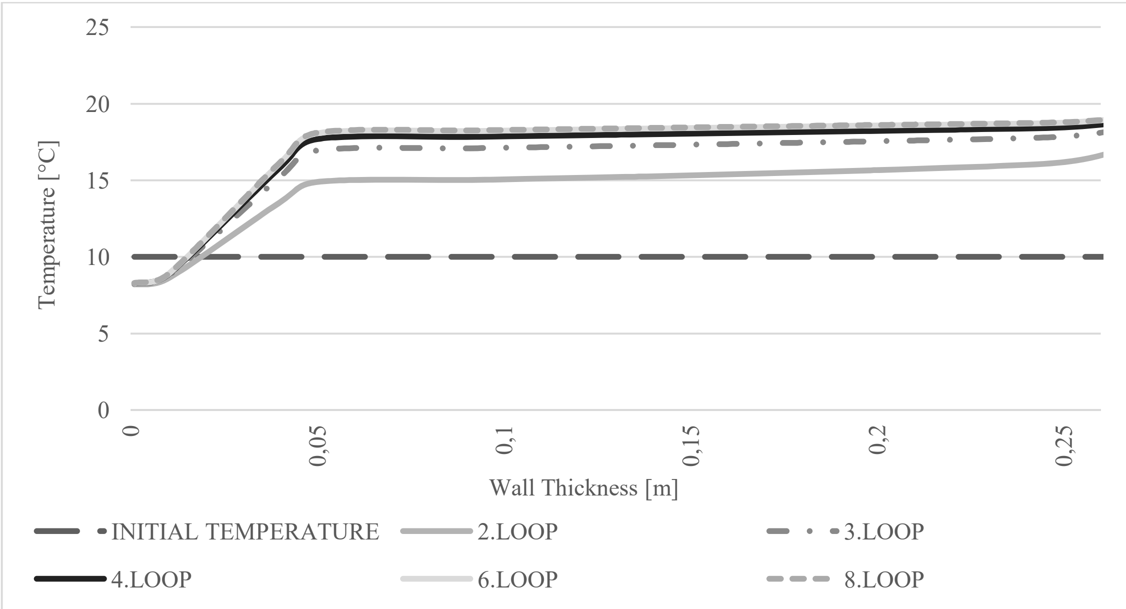


Figure 6.2. Sample of loop structure on the basis of distribution of temperature to the wall

In this study the iteration is repeated at minimum 5 times. Temperature values converged after first loop. Hence initial temperature values of inside of the wall were defined by using last loop results. Exterior insulated wall structure iteration has 8 loops for until the condition is True or until it becomes True. Table 6.1 shows a sample of iteration according to wall coordinates for exterior wall in İzmir.

Table 6.1. Sample of iteration

COORDINATES	INITIAL TEMPERATURE	2.LOOP	4.LOOP	6.LOOP	8.LOOP
0.001	10	8.19434	8.27801	8.28907	8.29053
0.01	10	8.58362	8.82604	8.85808	8.86231
0.04	10	13.55427	15.82406	16.12400	16.16364
0.05	10	14.88728	17.69518	18.06623	18.11527
0.09	10	15.01770	17.83731	18.20991	18.25915
0.1	10	15.05887	17.87298	18.24485	18.29400
0.14	10	15.25803	18.01654	18.38107	18.42924
0.15	10	15.31639	18.05270	18.41430	18.46208
0.19	10	15.58358	18.19865	18.54423	18.58989
0.2	10	15.65866	18.23550	18.57602	18.62102
0.21	10	15.73697	18.27249	18.60755	18.65183
0.25	10	16.17396	18.46000	18.76209	18.80201
0.268	10	17.18667	18.87081	19.09336	19.12277

Figure 6.3 presents distribution temperatures of sandwich insulated wall for north orientation in Erzurum with January data. Indoor air temperature is regarded 20°C in winter period. For this figure the evaluated times are; 24.00, 18.00, 12.00 and 06.00. The breaking points symbolize location of insulation material. Sandwich wall is better than exterior and interior wall insulation type for Erzurum.

And the other cities, namely Ankara and İstanbul's sample graphical solutions for daily conductive temperature distributions and heat flow are given in Appendix G, Figure G1 to G4 and Appendix H, Figure H1 to H4, respectively

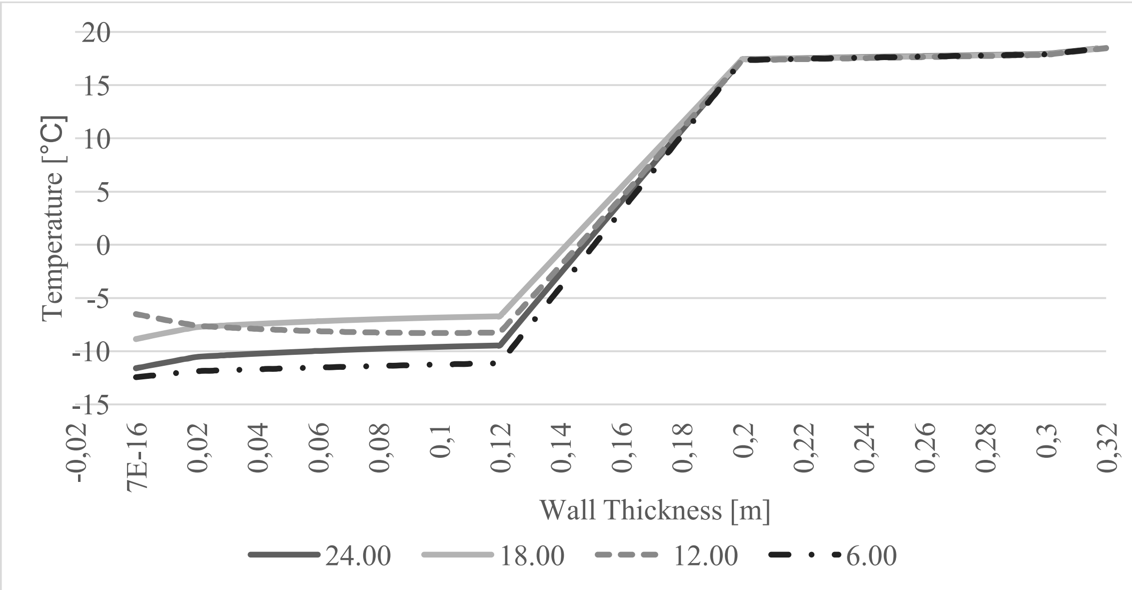


Figure 6.3. Sandwich Wall Temperature Distribution Across the Wall Thickness at Different Times of the Day for North Facing Wall in January in Erzurum.

In Figure 6.4 shows heat conduction through a sandwich wall insulation type in residential building in Erzurum. Indoor air temperature is 20°C and outside temperature value as of January data were used. Insulated wall for north facing significantly reduce fluctuations at inside surface. Besides, it is seen that temperatures of north facing wall has higher peak values than those of east west and south facing walls in winter period.

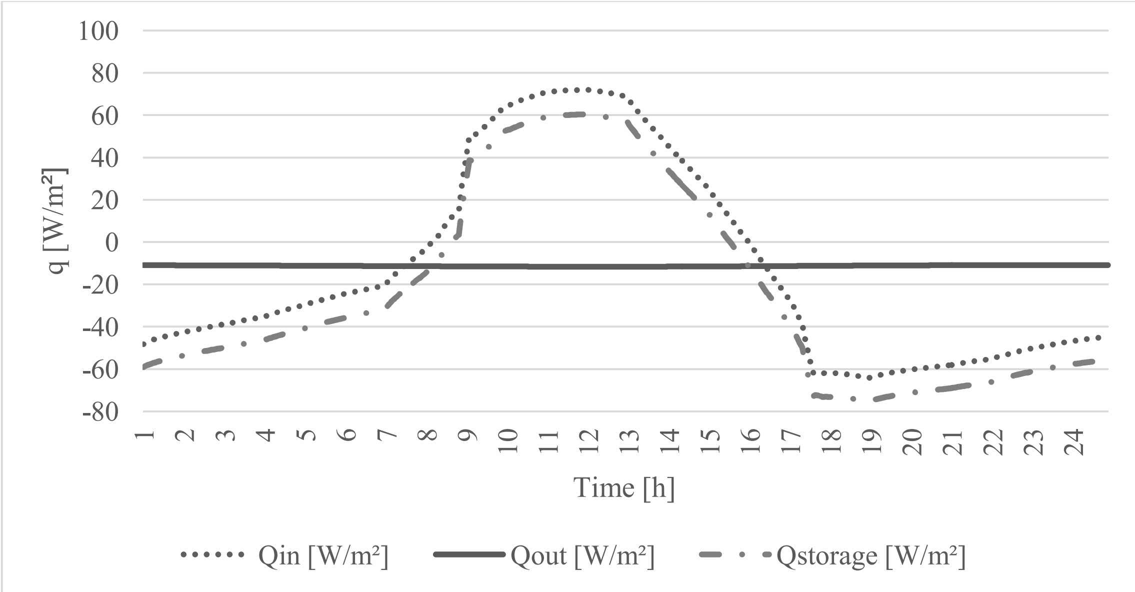


Figure 6.4. Hourly Variation of Inside Surface Heat Flux of Sandwich Wall Structures Under Optimal Insulation Conditions for January North Facing in Erzurum.

Figure 6.5 illustrates temperature distribution of monthly average of the daily values in Erzurum for east facing wall in January meteorological data. Indoor air temperature is accepted 20 °C in winter period. This figure has 4 different hours in a day. The selected times are; 24.00, 18.00, 12.00 and 06.00. The insulation layer causes a substantial temperature drop across its thickness. It is seen that the greatest temperature drop and minimum temperature fluctuations when insulation is placed on the sandwich wall.

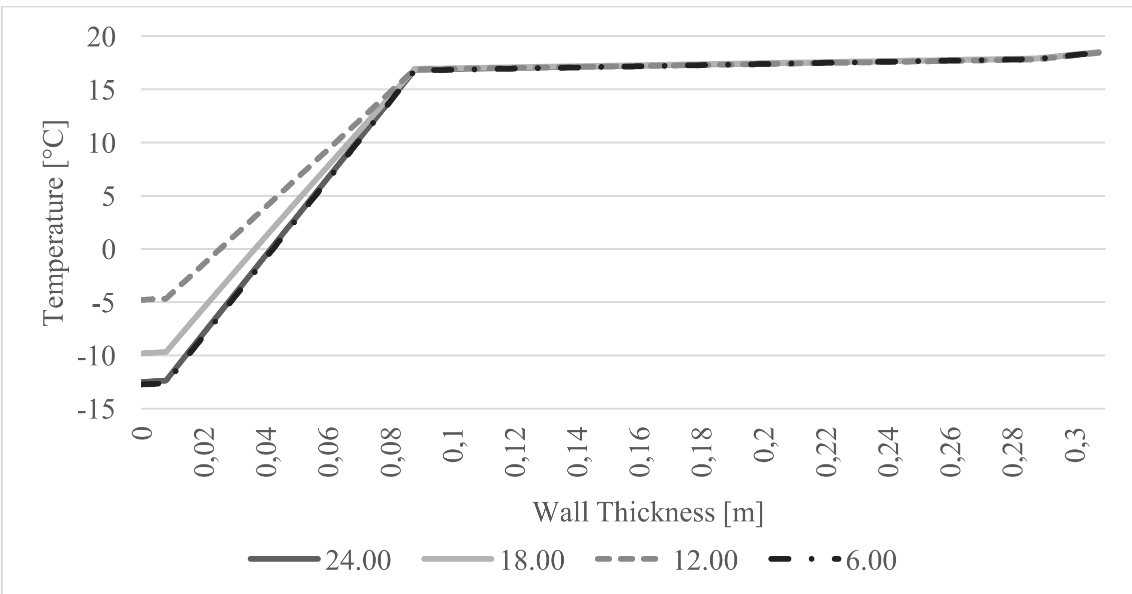


Figure 6.5. Exterior Wall Temperature Distribution Across the Wall Thickness at Different times of the day for East Facing Wall in January in Erzurum.

Figure 6.6 shows hourly variation of inside surface heat flux of external insulated wall structures under optimal insulation conditions at 0.08 m insulation thickness for January in Erzurum for east direction. It is seen that the maximum heat flux peak load is in morning time in winter for exterior wall insulation gives the smallest fluctuation.

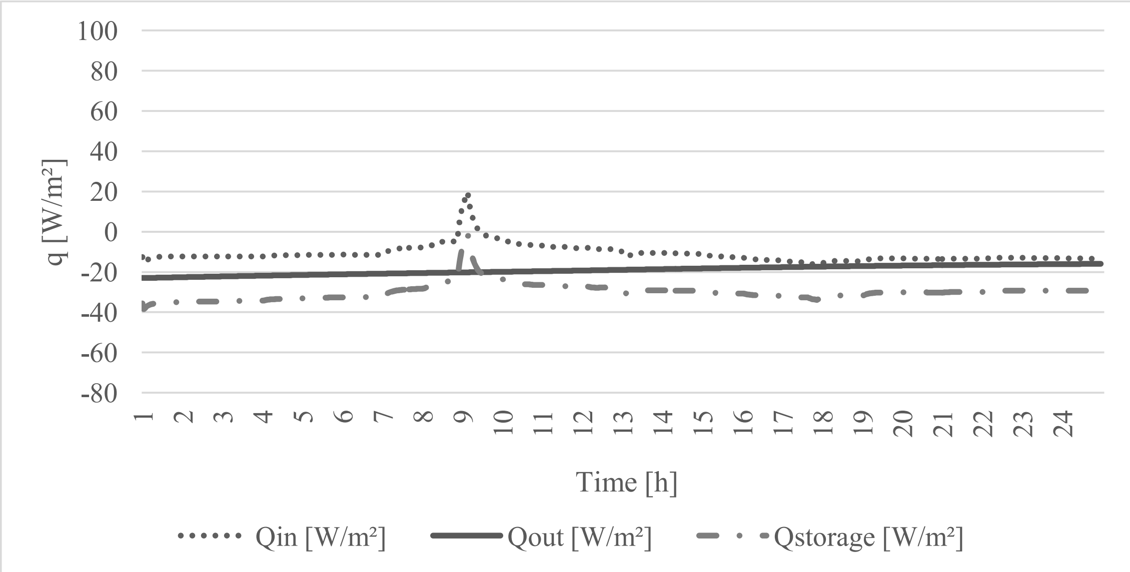


Figure 6.6. Hourly Variation of Inside Surface Heat Flux of Exterior Wall Structures Under Optimal Insulation Conditions for January East Facing in Erzurum.

Temperature distribution across thickness of interior insulated wall is shown in Figure 6.7 with a time interval of 4 hours during a 24 hours period for January in residential building in Erzurum. Room air temperature is selected 20°C. The insulation layer causes a substantial temperature drop across its thickness.

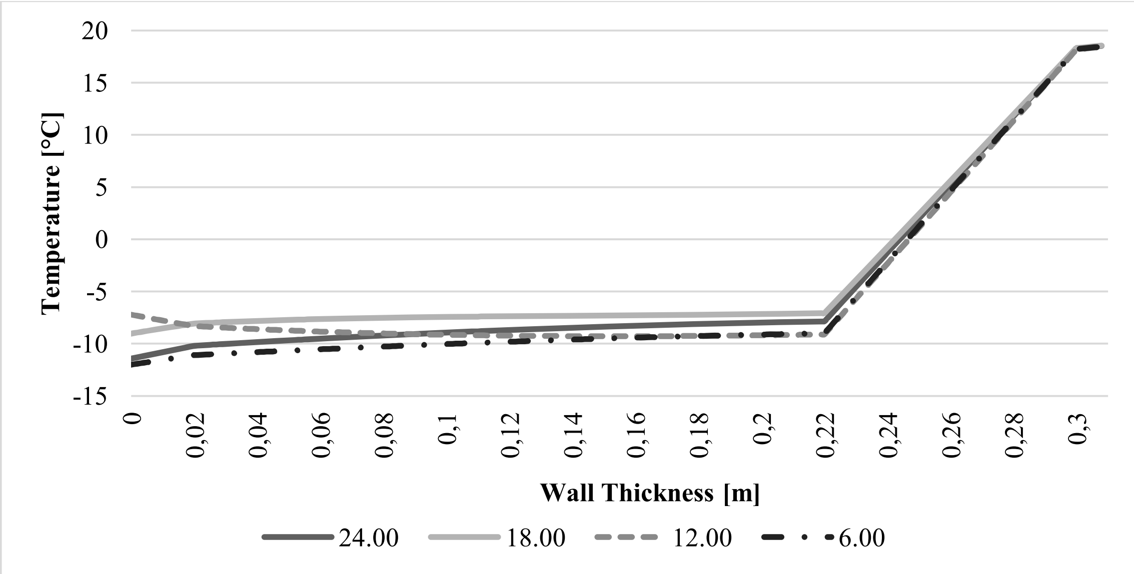


Figure 6.7. Interior Wall Temperature Distribution Across the Wall Thickness at Different Times of the Day for West Facing Wall in January in Erzurum.

Figure 6.8 shows hourly variation of inside surface heat flux of internal insulated wall structures for winter time in Erzurum for west direction in a day. Room air temperature is accepted 20°C and January meteorological data were used. It is seen that the maximum heat flux peak load is in midday hours in winter period. Also total heat loss is represented by $Q_{storage}$ [W/m^2] is equal, total of heat flux at indoor surface and outdoor surface of the wall.

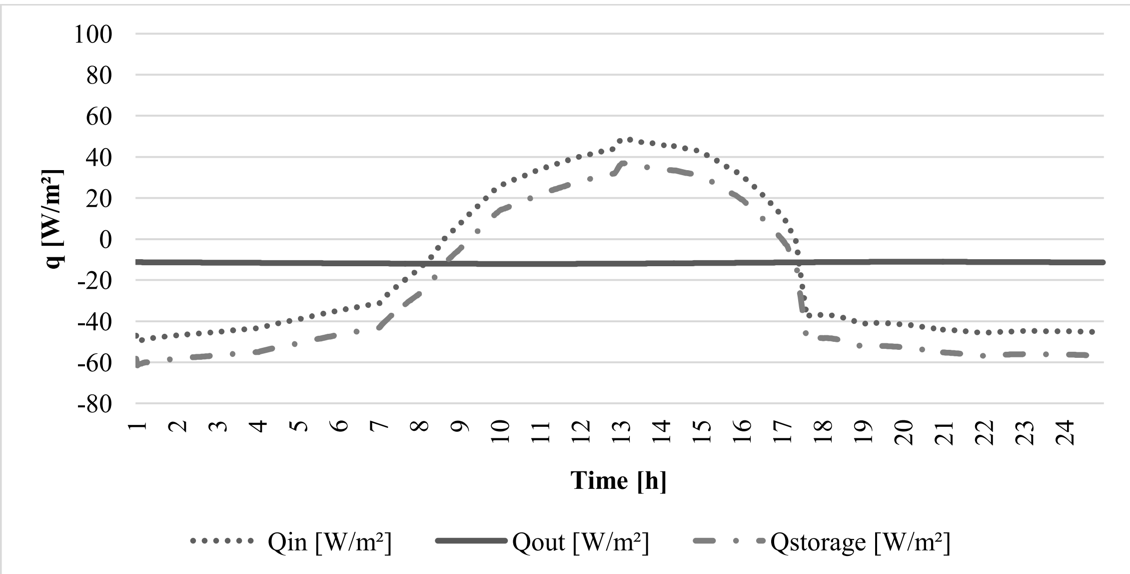


Figure 6.8. Hourly Variation of Inside Surface Heat Flux of Interior Wall Structures Under Optimal Insulation Conditions for January West Facing in Erzurum.

Figure 6.9 illustrates distribution temperatures of uninsulated insulated wall for south orientation in Erzurum with January data were used. Indoor air temperature is 20 °C. For this figure the evaluated times are; 24.00, 18.00, 12.00 and 06.00. It is noted that temperature fluctuations on the outside surfaces of uninsulated wall are fairly high.

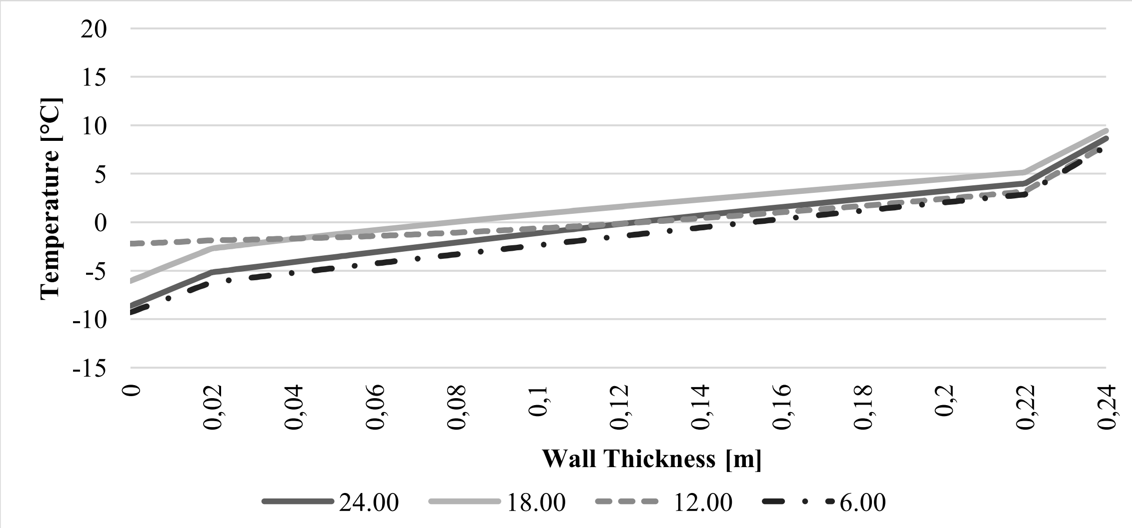


Figure 6.9. Uninsulated Wall Temperature Distribution Across the Wall Thickness at Different Times of the Day for South Facing Wall in January in Erzurum.

Figure 6.10 shows heat fluctuations of uninsulated wall for south orientation in Erzurum in January. Heat flux values have wide range according to insulated wall types. It is seen that, the maximum rate of heat loss is from uninsulated wall in winter time.

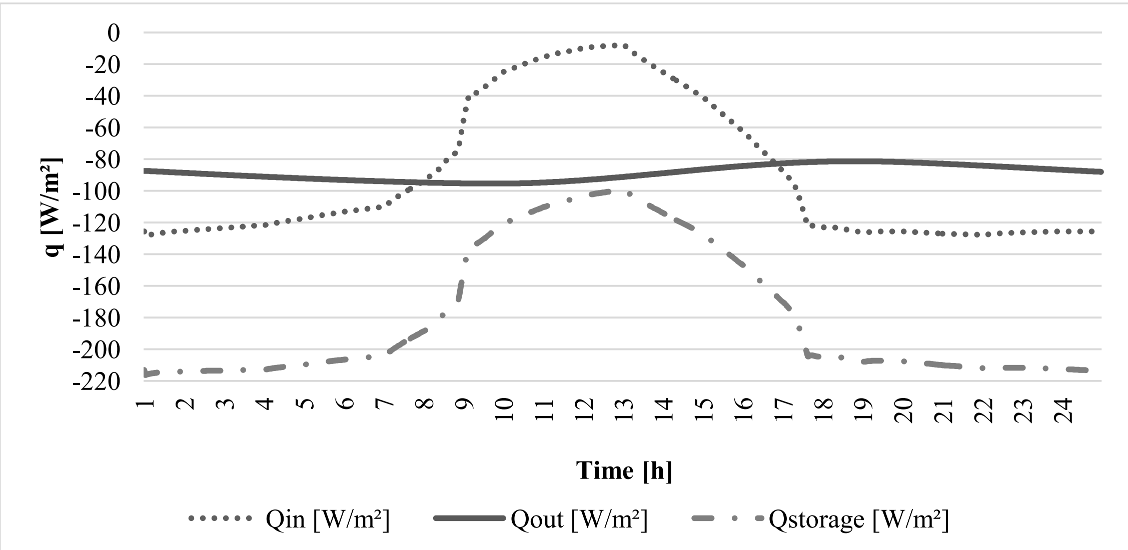


Figure 6.10. Hourly Variation of Inside Surface Heat Flux of Uninsulated Wall Structures Under Optimal Insulation Conditions for January South Facing in Erzurum.

Temperature distributions across sandwich wall thickness at different times with an interval of 4 hours in July are shown in Figure 6.11. And the numerical solution gives the temperature distribution across the composite wall thickness. In residential building temperature distribution is evaluated for İzmir. Room air temperature is assumed 24°C for summer period. In any building projected to function as a residence, sandwich wall thermal insulation should be opted for exterior wall design during summer and winter months.

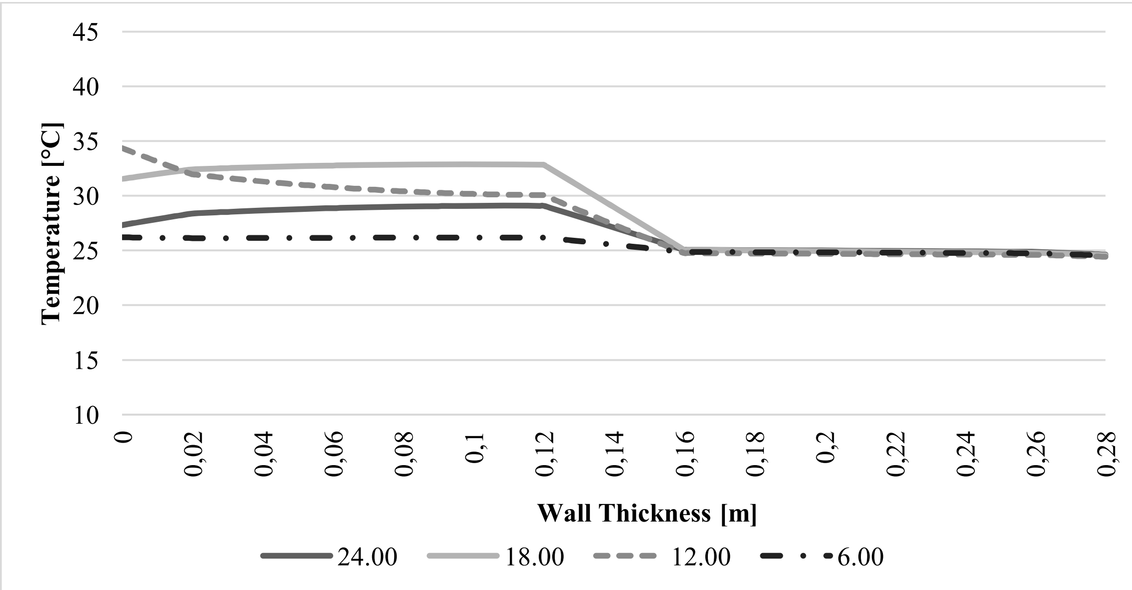


Figure 6.11. Sandwich Wall Temperature Distribution Across the Wall Thickness at Different Times of the Day for South Facing Wall in July in İzmir.

The insulation is now positioned within the wall structure. According to design of sandwich wall that protects the insulation material and improves the wall appearance, while influencing the heat transfer through the wall. The system is shown in Figure 6.12 and this figure shows inside surface temperatures of sandwich wall for south orientation in İzmir in summer period based on heat gain/loss from the wall.

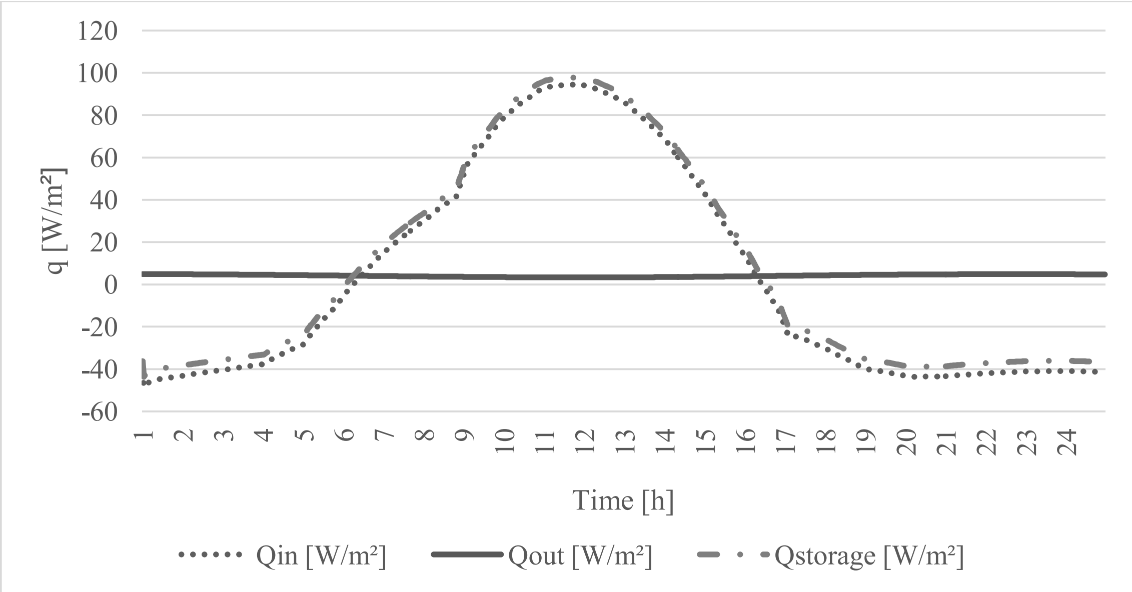


Figure 6.12. Hourly Variation of Inside Surface Heat Flux of Sandwich Wall Structures Under Optimal Insulation Conditions for July South Facing in İzmir.

Figure 6.13 represents the temperature distribution across the wall thickness at different times of the day for west facing wall in July for interior wall, for extruded polystyrene insulated wall in 4 cm optimum insulation thickness in İzmir summer period. The time interval of 4 hours during a 24 hours period for a day. It is seen that the optimum insulation significantly reduces temperature fluctuations.

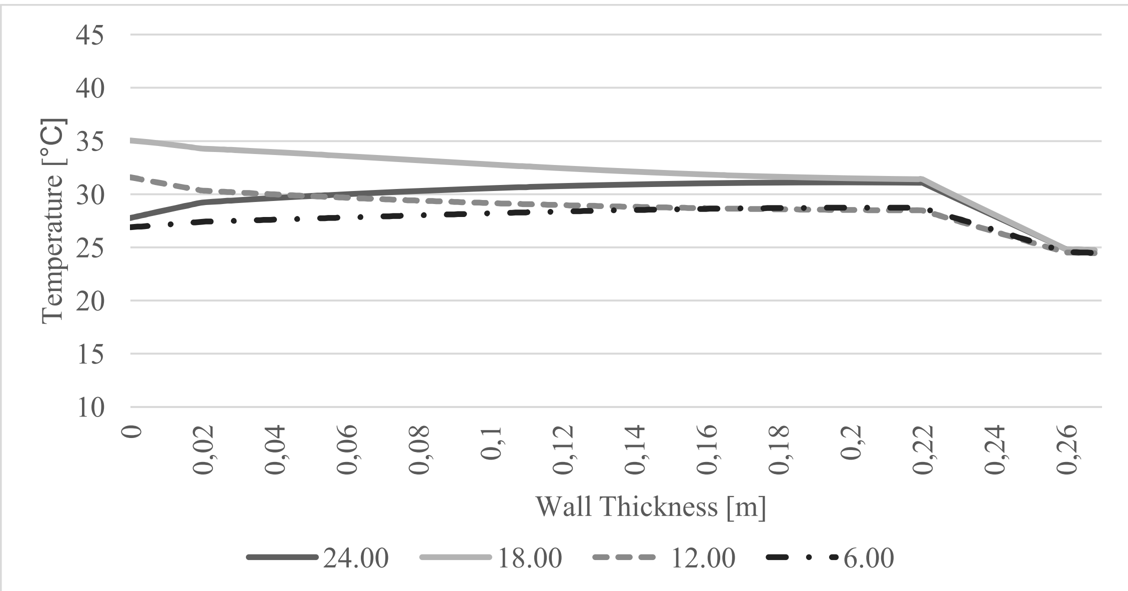


Figure 6.13. Interior Wall Temperature Distribution Across the Wall Thickness at Different Times of the Day for West Facing Wall in July in İzmir.

Figure 6.14 illustrates heat conduction through an interior wall insulation type in residential building in İzmir. Indoor air temperature is 24°C and outside temperature value as of July data were used. It is seen that the maximum heat flow is at July in west direction this is because the combined effect of solar radiation and ambient temperature will dominate at this month.

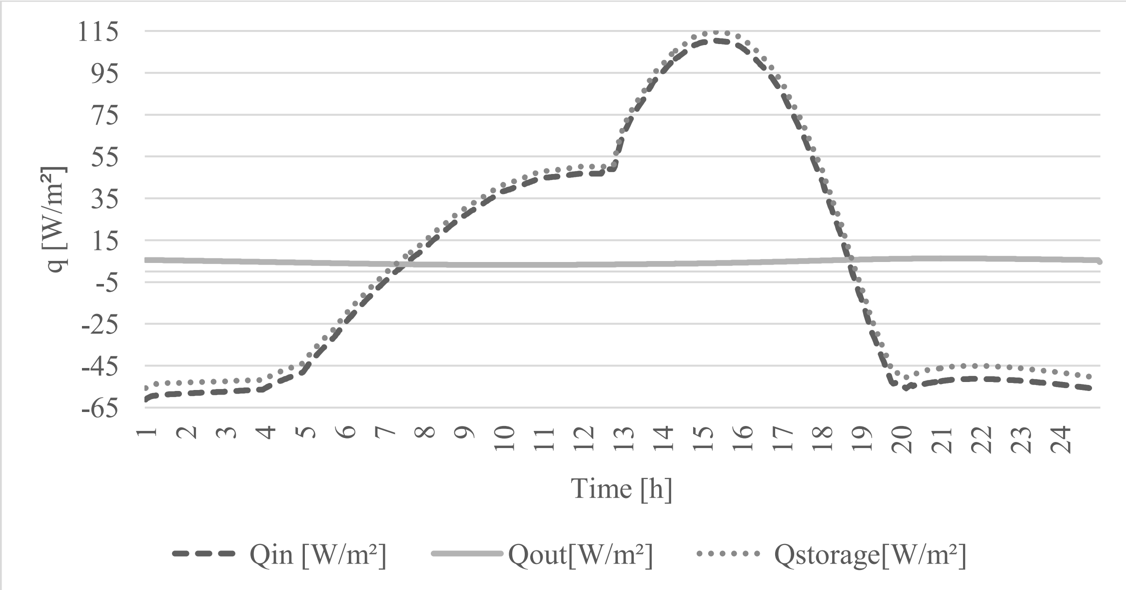


Figure 6.14. Hourly Variation of Inside Surface Heat Flux of Interior Wall Structures Under Optimal Insulation Conditions for July West Facing in İzmir.

Temperature distribution across thickness of uninsulated wall is shown in Figure 6.15 with a selected time that 06.00, 12.00, 18.0 and 24.00 in a day of July. Room air temperature is accepted 24°C and also the temperature fluctuations on the inside and outside surface of uninsulated wall are fairly high by comparison with all insulation types.

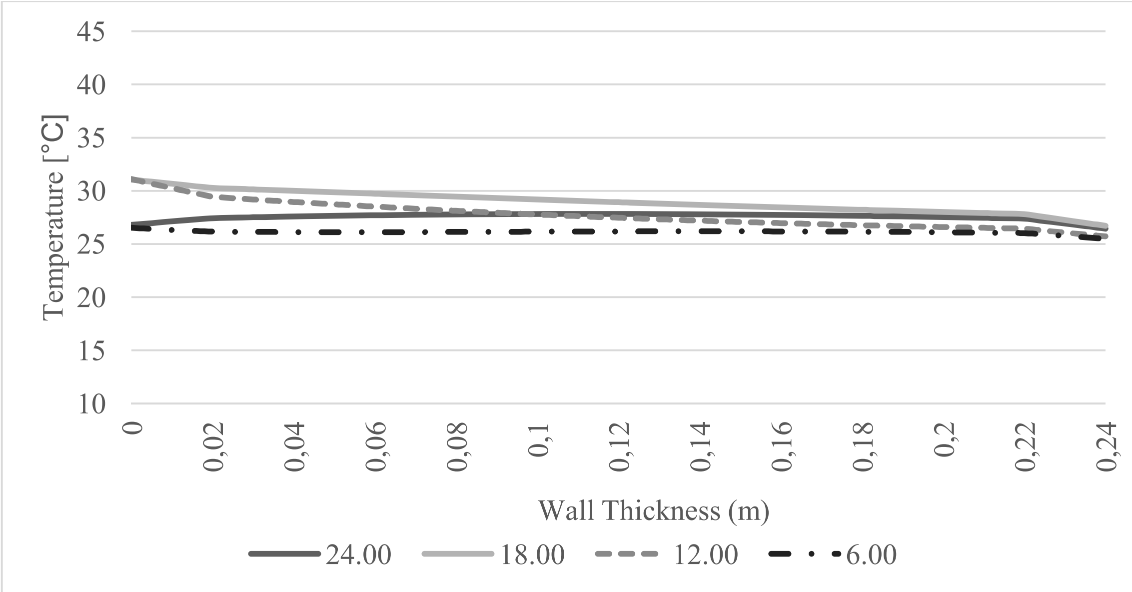


Figure 6.15. Uninsulated Wall Temperature Distribution Across the Wall Thickness at Different Times of the Day for North Facing Wall in July in İzmir.

Figure 6.16 shows heat fluctuations of uninsulated wall for north orientation in İzmir in summer period. Indoor air temperature is 24°C and for outside temperature meteorological data is used for the heat flux calculation also the wall structure's thermophysical properties is accepted based on in referenced number 14 According to those calculations it is seen that, the maximum rate of heat gain/loss is from uninsulated wall.

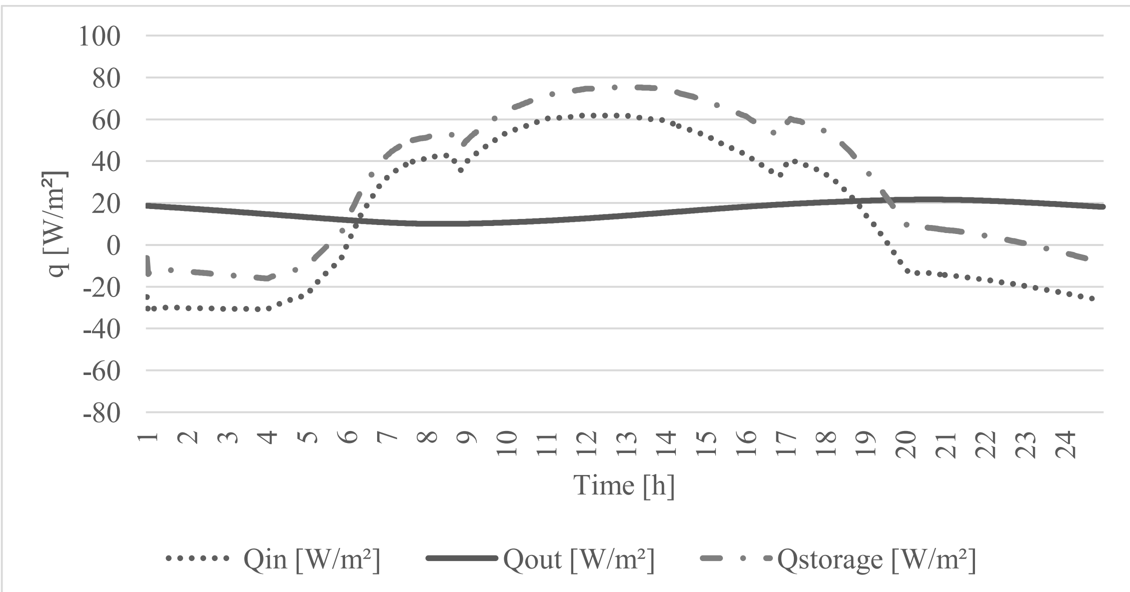


Figure 6.16. Hourly Variation of Inside Surface Heat Flux of Uninsulated Wall Structures Under Optimal Insulation Conditions for July North Facing in İzmir.

In Figure 6.17 shows the temperature distribution in exterior insulated wall type in residential building wall in İzmir. Room air temperature is selected 24°C in July for east direction of wall. These temperature values are chosen every 4 hours in a day. In wall construction, after the outside plaster, 0.04 cm extrude polystyrene insulation material is inserted. And the temperature fluctuation is fixed after the insulation layer in wall structure.

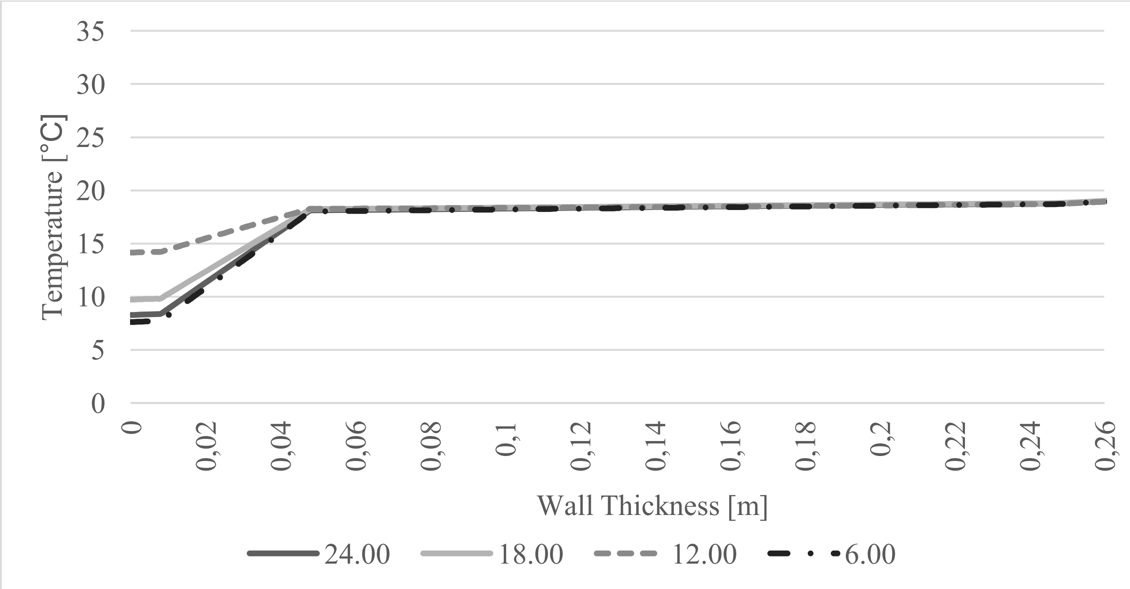


Figure 6.17. Exterior Wall Temperature Distribution Across the Wall Thickness at Different Times of the day for East Facing Wall in July in İzmir.

Figure 6.18 shows hourly variation of inside surface heat flux of external insulated wall structures for July in İzmir for east direction. It is seen that the maximum heat flux peak load is in morning time in summer. For exterior wall insulation gives the smallest fluctuation.

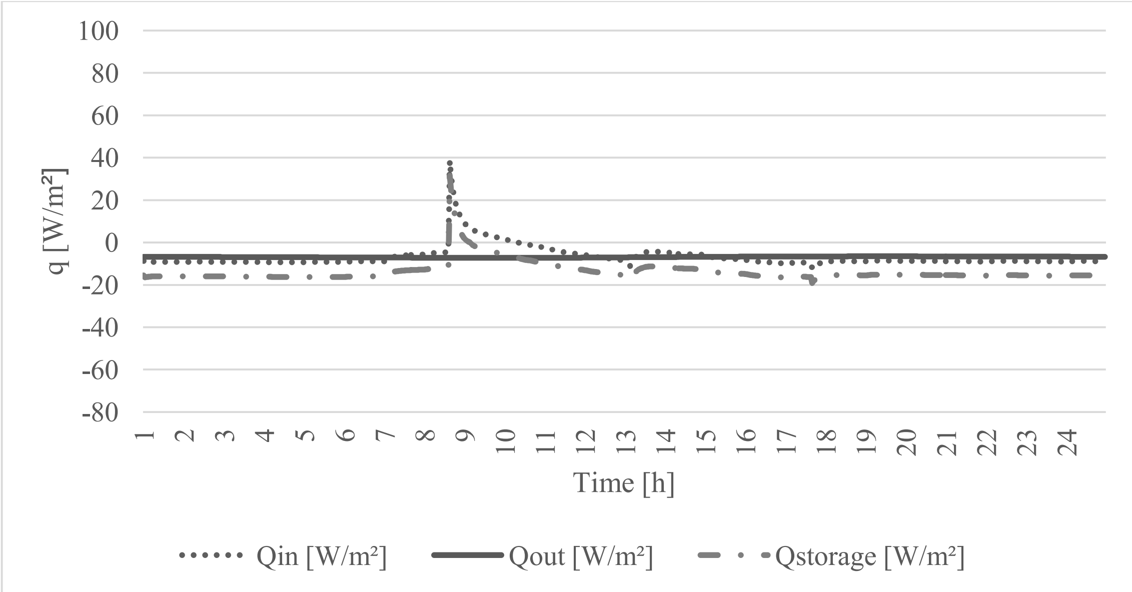


Figure 6.18. Hourly Variation of Inside Surface Heat Flux of Sandwich Wall Structures Under Optimal Insulation Conditions for July East Facing in İzmir.

The yearly transmission heating and cooling loads, daily average obtained under optimum insulation thickness and selected U-value (overall heat transfer coefficient) based on TS-825 [5] for the 4 zone are indicated. In Table 6.2 illustrates the daily conductive heat flow through a uniform plane wall is calculated for İzmir. The calculations result are denominated in watt-hour (Wh/m²day) which is a unit of energy equivalent to one watt of power expended for one hour of time per square meter for a day. Indoor air temperature is accepted 20°C for winter and 24°C for summer period. And also according to all orientations, considered insulation materials in the analysis were extrude polystyrene insulation. In compliance with this, the heat gain/loss are calculated in order that uninsulated wall, exterior wall, interior wall and sandwich wall types.

In Table 6.2, insulated wall for all orientations significantly reduce fluctuations compared with uninsulated wall. And according to direction of wall the lowest cooling load is provided for north facing wall while the lowest heating load is obtained for south facing wall in summer period.

However in winter period maximum heat loss is from north direction in comparison with east, west and south orientations. The heating transmission loads is greater than cooling transmission loads for all orientations. It showed that the approximate value is obtained in external insulated, internal insulated and sandwich wall insulation types. Besides, it still can be seen in the studies in winter and summer time sandwich wall is proper than other type of insulations. And the other cities, namely Ankara, Erzurum and İstanbul are given in Appendix H, Figure H1 to H3, respectively.

Table 6.2. Uninsulated and Insulated Wall Types Daily Conductive Heat Flow Through a Uniform Plane Wall Comparison, Considering Wall Orientations Both Winter and Summer for İzmir.

IZMIR			Unisulated Wall (Wh/m²day)	Exterior Wall Insulation (Wh/m²day)	Interior Wall Insulation (Wh/m²day)	Sandwich Wall Insulation (Wh/m²day)
East	Winter	**20°C**	-723.623	-164.792	-165.996	-162.293
	Summer	**24°C**	479.943	108.762	109.620	109.318
South	Winter	**20°C**	-630.108	-151.855	-144.600	-142.397
	Summer	**24°C**	439.804	101.354	100.406	98.766
West	Winter	**20°C**	-722.432	-164.779	-165.766	-162.135
	Summer	**24°C**	481.682	108.262	109.842	107.657
North	Winter	**20°C**	-761.702	-170.167	-174.736	-170.456
	Summer	**24°C**	386.573	91.983	88.251	87.064
TS825	Winter	**20°C**	-842.578	-191.122	-193.098	-188.950
	Summer	**24°C**	341.389	77.437	78.238	76.557

Table 6.3 represents the relative error equation to inferred results and TS-825 results according to different types of wall model and their orientation. These calculations are based on insulation thickness and selected U-value (overall heat transfer coefficient) are indicated. This relative error of the measurement shows how large the error is in relation to the situated value.

Let the measured value of the study be x and the TS-825 value x_0. Then the relative error is defined by;

$$\frac{x_0 - x}{x} \rightarrow \frac{Q_{TS825} - Q_{calc}}{Q_{calc}} \tag{6.1}$$

As a consequences of these calculations are defined the relation between measured data and TS-825 value. And the other cities, namely Ankara, Erzurum and İstanbul are given in Appendix I, Figure I1 to I3, respectively.

Table 6.3. Uninsulated and Insulated Wall Types Daily Conductive Heat Flow Inferred Results Comparison With TS-825 Results Considering Wall Orientations Both Winter and Summer for İzmir.

IZMIR			Unisulated Wall (Wh/m²day)	Exterior Wall Insulation (Wh/m²day)	Interior Wall Insulation (Wh/m²day)	Sandwich Wall Insulation (Wh/m²day)
East	Winter	**20°C**	-0.164	-0.160	-0.163	-0.164
	Summer	**24°C**	0.289	0.288	0.286	0.300
South	Winter	**20°C**	-0.337	-0.259	-0.335	-0.327
	Summer	**24°C**	0.224	0.236	0.221	0.225
West	Winter	**20°C**	-0.166	-0.160	-0.165	-0.165
	Summer	**24°C**	0.291	0.285	0.288	0.289
North	Winter	**20°C**	-0.106	-0.123	-0.105	-0.109
	Summer	**24°C**	0.117	0.158	0.113	0.121

CHAPTER 7

CONCLUSION

The insulation application is a standout amongst the most substantial systems to conserve energy in building structure. So choosing the appropriate insulation material and deciding the optimum insulation thickness is vital for energy saving and energy storing. The optimum insulation thickness and how to locate the insulation material of walls structure is differ from each other in accordance with varied climatic condition.

TS-825 Thermal Insulation Standard in Buildings [5], calculated optimum insulation thickness and the U value (overall heat transfer coefficient) for the 4 zones situated, are based on the heating load. In this study, these cities are selected from four climate zones were evaluated according to summer and winter conditions is based on optimum insulation thicknesses. Based on the calculations made for the cities, recommended U values (overall heat transfer coefficient) to taken into account as a primary consideration, in terms of energy efficiency is not sufficient the point in question. According to these, this study deals with the heat transfer characteristics of building walls and wall's orientations. The investigation is carried out for 4 directions (North, East, South, West) and 4 different climatic in Turkey. The selected cities are Ankara, Erzurum, İstanbul and İzmir. For this purpose, insulation is placed at outside, inside and middle of wall. Thermal and environmental parameters for insulated building walls of in a dynamic climatic condition are numerically investigated by using an implicit finite-difference method developed in Visual Basic Program.

Results shows that the approximate value is obtained in exterior wall insulation, interior wall insulation and sandwich wall insulation types. However, in any building projected to function as a residence or HVAC system work hours are stable are assumed building, sandwich wall thermal insulation should be opted for in the design of exterior wall construction during both summer and winter months.

All outcomes acquired in this time dependent study will be extremely helpful from thermal comfort and energy conservation perspective, and reduce the capacity of heating and cooling system and consequently choosing the insulation type for building envelope in different climatic condition.

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APPENDIX A

GUIDELINE FOR ROOM AIR TEMPERATURE

Type of Space	°F		°C	
	Summer	Winter	Summer	Winter
Residences, apartments, hotel and motel guest rooms, convalescent homes, offices, conference rooms, classrooms, courtrooms, and hospital patient rooms	74–78	68–72	23–26	20–22
Theaters, auditoriums, churches, chapels, synagogues, assembly halls, lobbies, and lounges	76–80	70–72	24–27	21–22
Restaurants, cafeterias, and bars	72–78	68–70	22–26	20–21
School dining and lunch rooms	75–78	65–70	24–26	18–21
Ballrooms and dance halls	70–72	65–70	21–22	18–21
Retail shops and supermarkets	74–80	65–68	23–27	18–20
Medical operating rooms[a]	68–76	68–76	20–24	20–24
Medical delivery rooms[a]	70–76	70–76	21–24	21–24
Medical recovery rooms and nursery units	75	75	24	24
Medical intensive care rooms[a]	72–78	72–78	22–26	22–26
Special medical care nursery units[a]	75–80	75–80	24–27	24–27
Kitchens and laundries	76–80	65–68	24–27	18–20
Toilet rooms, service rooms, and corridors	80	68	27	20
Bathrooms and shower areas	75–80	70–75	24–27	21–24
Steam baths	110	110	43	43
Warm air baths	120	120	49	49
Gymnasiums and exercise rooms	68–72	55–65	20–22	13–18
Swimming pools	75 or above	75	24	24
Locker rooms	75–80	65–68	24–27	18–20
Children's play rooms	75–78	60–65	24–26	16–18
Factories and industrial shops	80–85	65–68	27–29	18–20
Machinery spaces, foundries, boiler shops, and garages	—	50–60	—	10–16
Industrial paint shops	—	75–80	—	24–27

[a] Variable temperature range required with individual room control.

Figure A1. Guideline for Room Air Temperature (ASHRAE)

APPENDIX B

CLIMATE AND COMFORT ZONES JANUARY AND JULY DATA

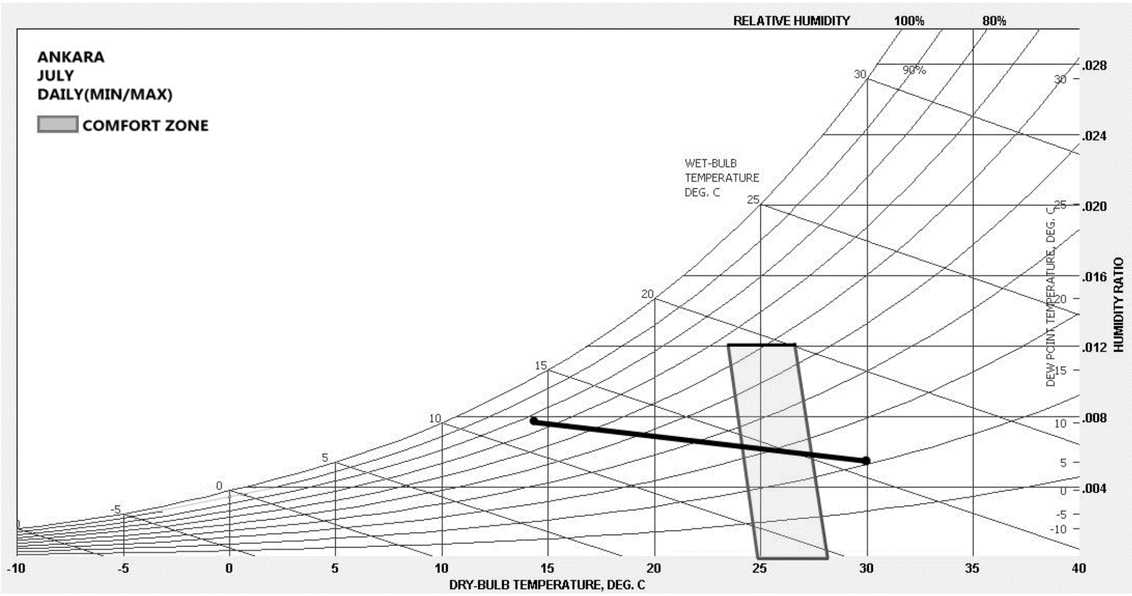

Figure B1. Climate and Comfort Zones January in Ankara.

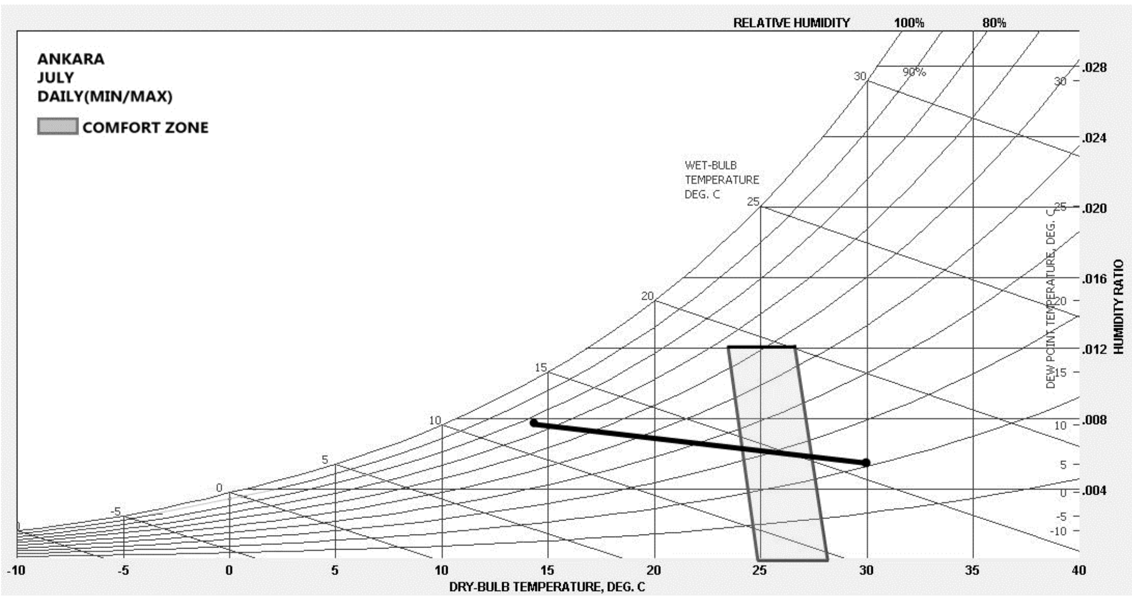

Figure B2. Climate and Comfort Zones July in Ankara.

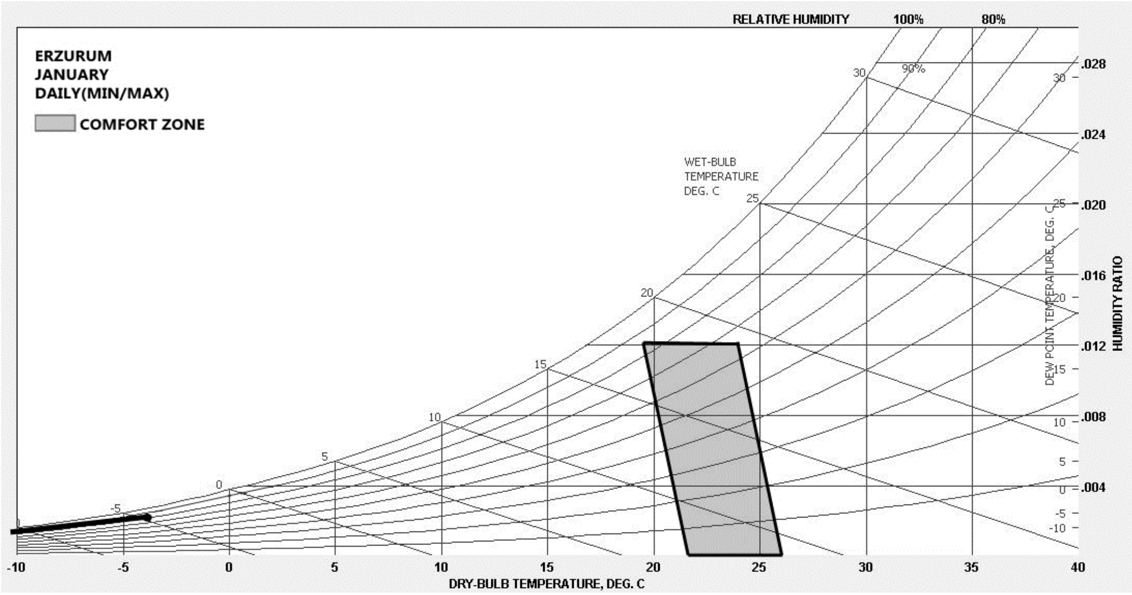

Figure B3. Climate and Comfort Zones January in Erzurum.

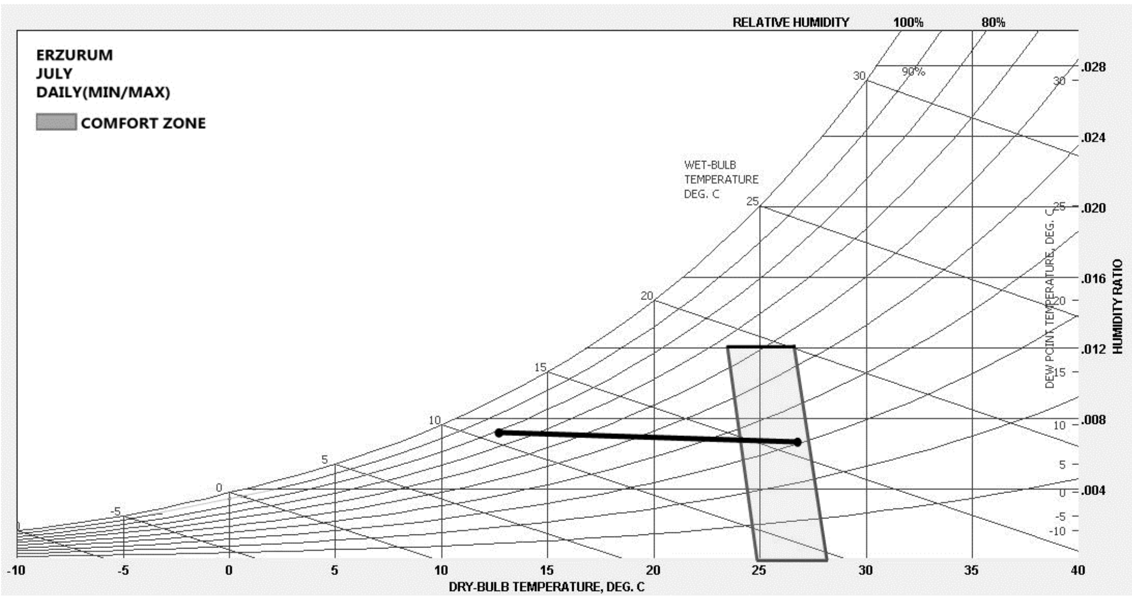

Figure B4. Climate and Comfort Zones July in Erzurum.

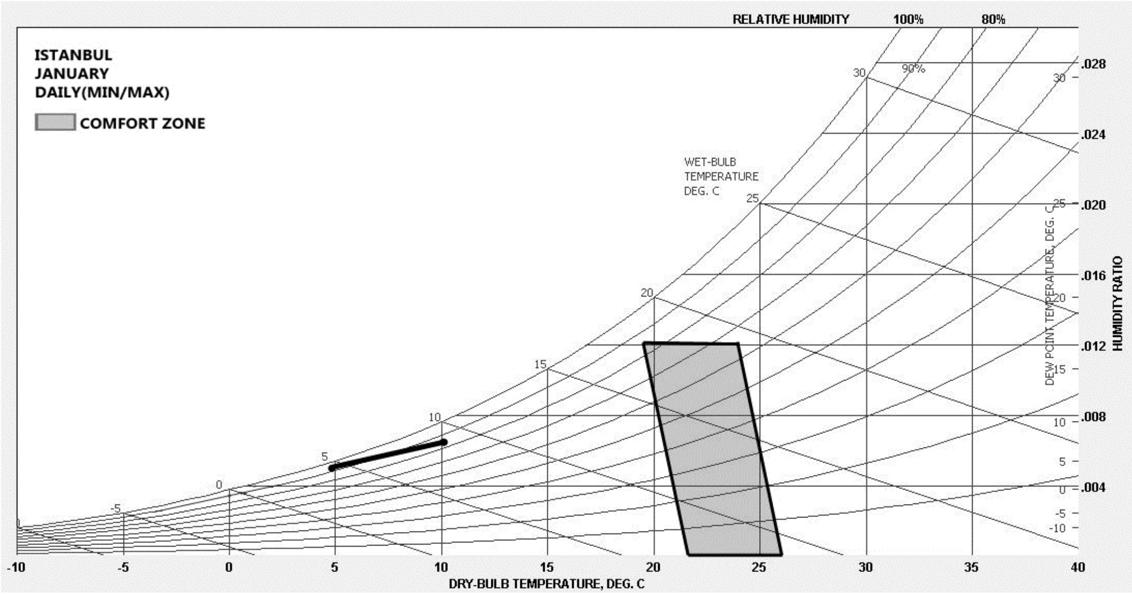

Figure B5. Climate and Comfort Zones January in İstanbul

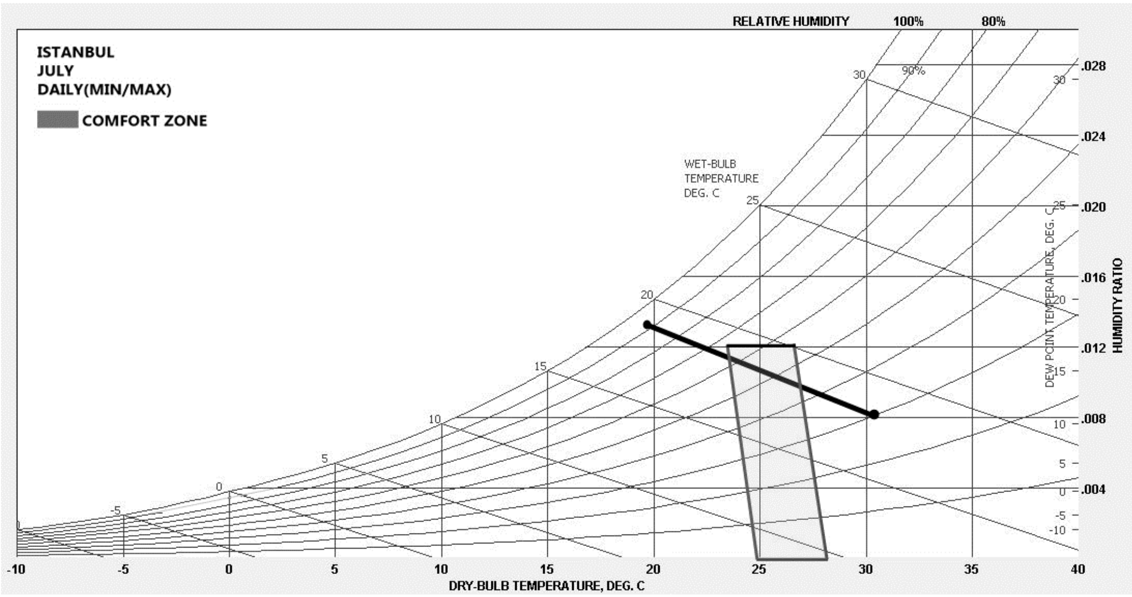

Figure B6. Climate and Comfort Zones July in İstanbul

APPENDIX C

MONTHLY AVERAGE OF THE DAILY TEMPERATURE DISTRIBUTIONS

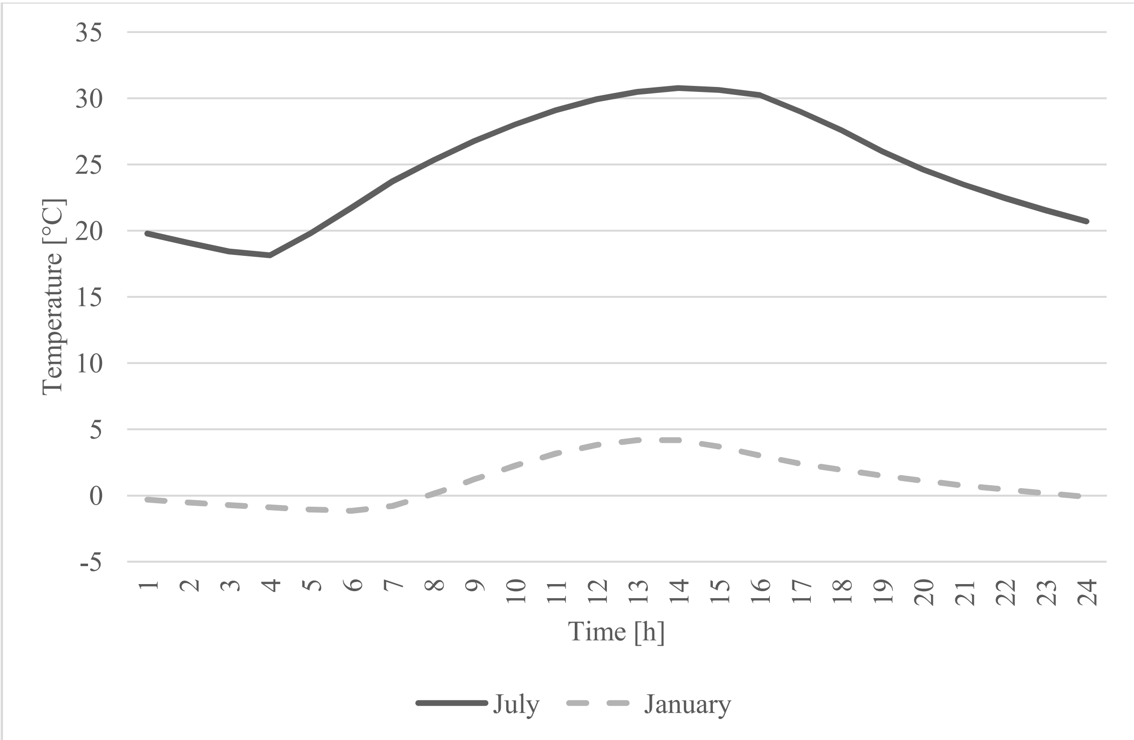

Figure C1. Monthly Average of the Daily Temperature Distribution of Ankara

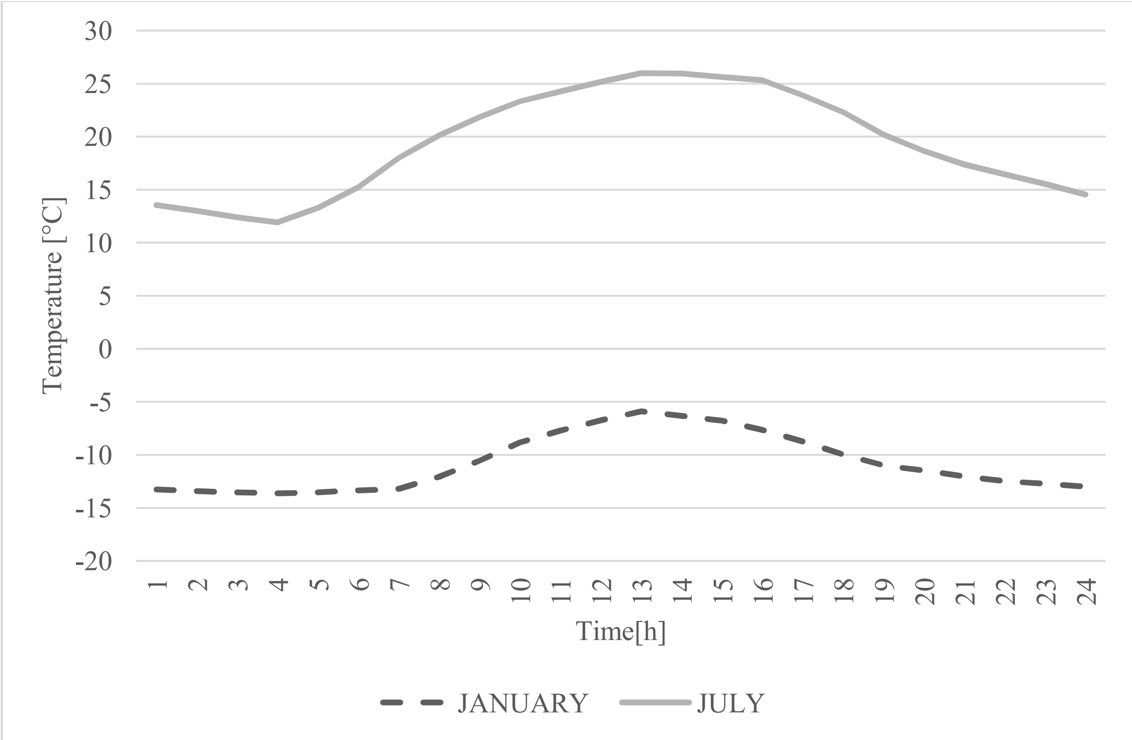

Figure C2. Monthly Average of the Daily Temperature Distribution of Erzurum

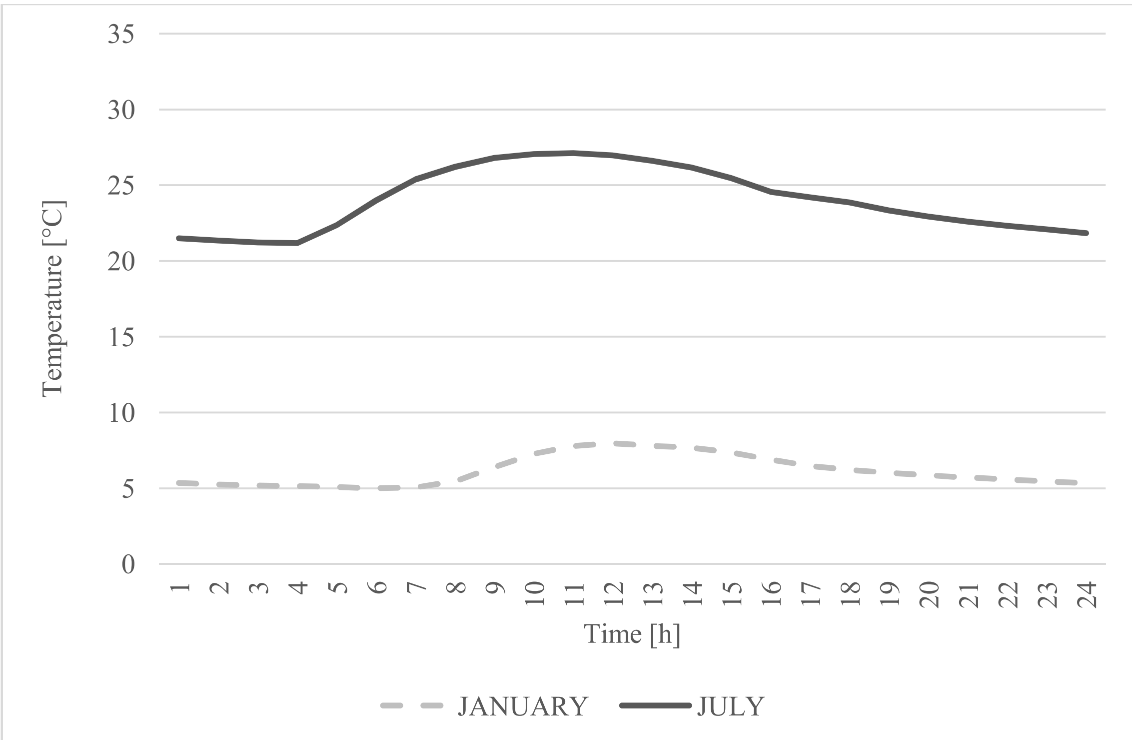

Figure C3. Monthly Average of the Daily Temperature Distribution of İstanbul

APPENDIX D

MONTHLY AVERAGE OF THE DAILY SOLAR RADIATION DISTRIBUTION

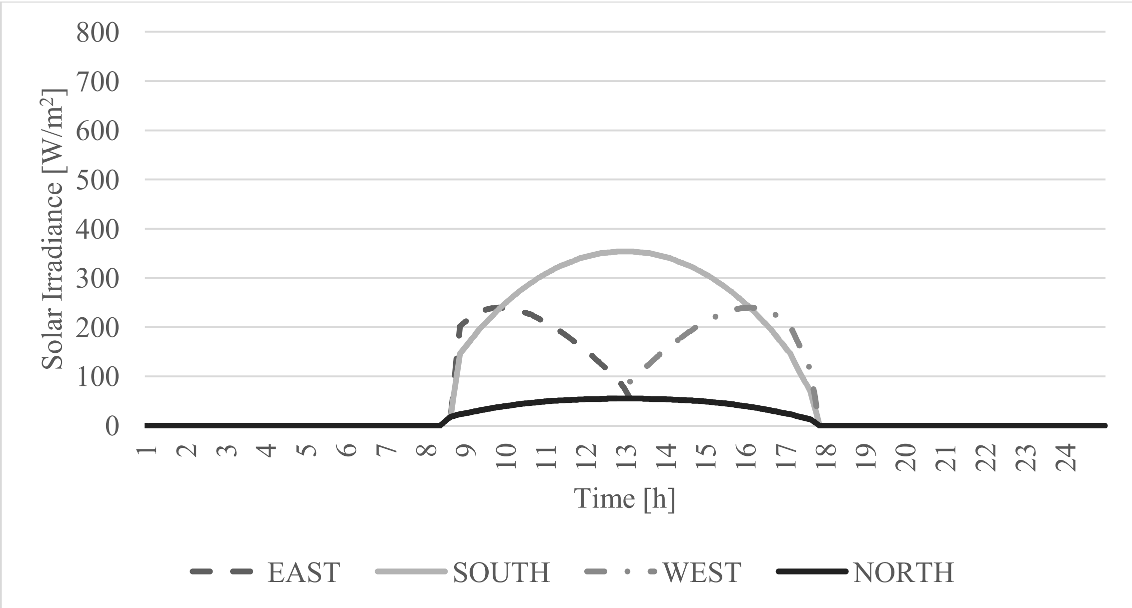

Figure D1. Ankara January Solar Radiation Monthly Average of the Daily Distribution

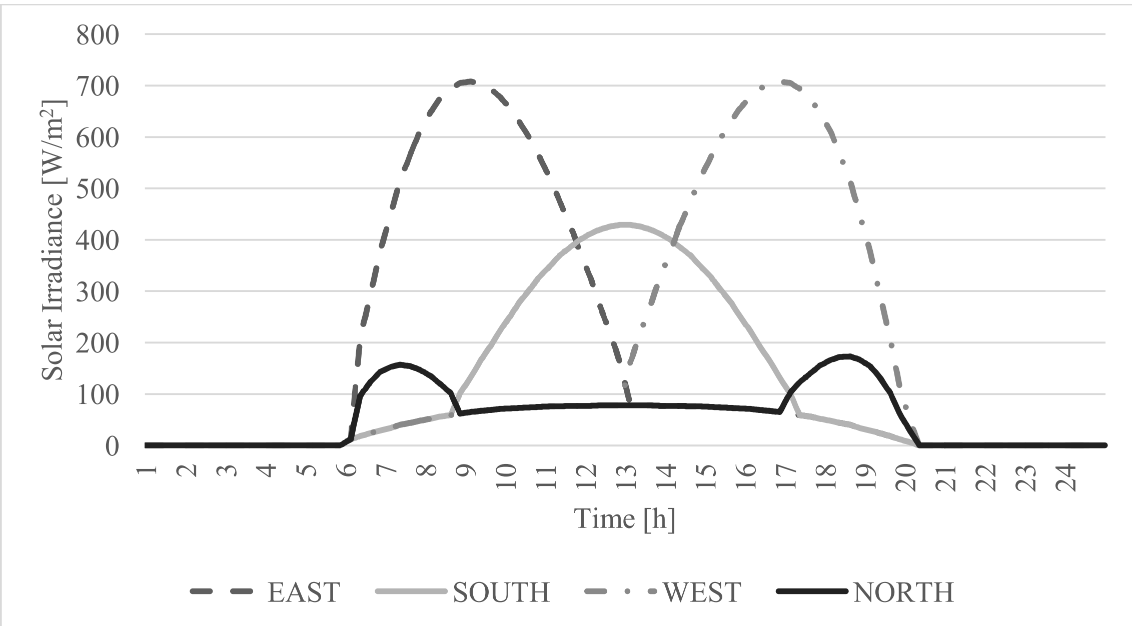

Figure D2. Ankara July Solar Radiation Monthly Average of the Daily Distribution

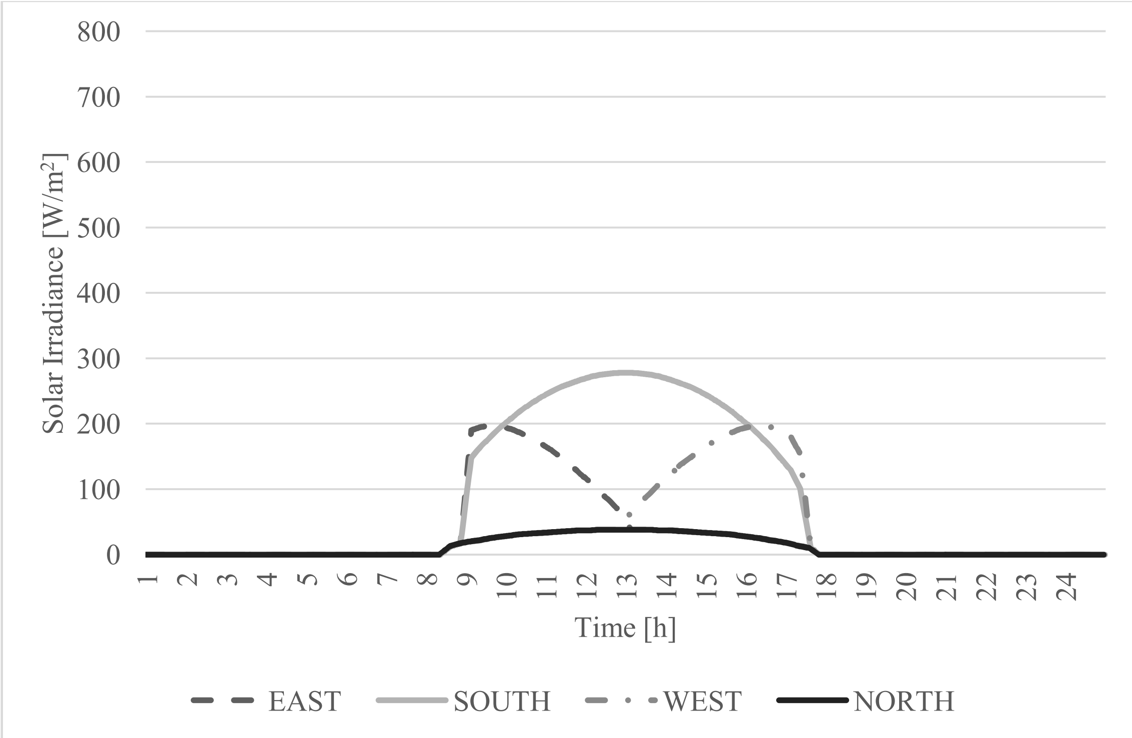

Figure D3. Erzurum January Solar Radiation Monthly Average of the Daily Distribution

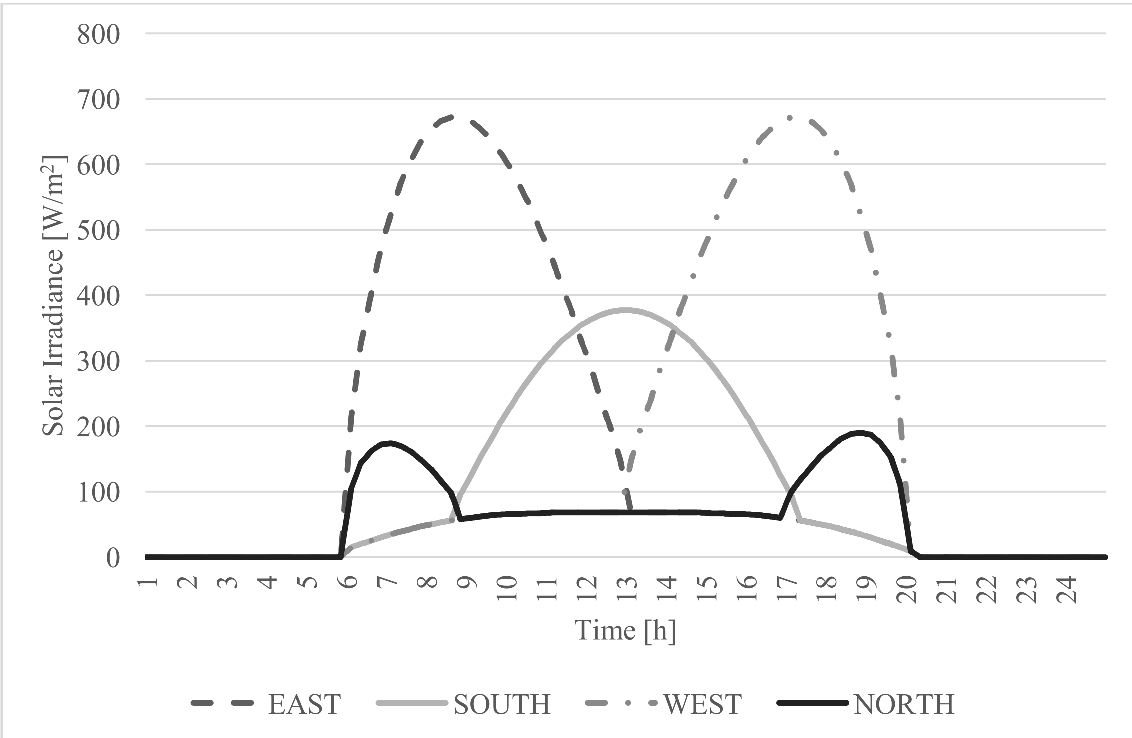

Figure D4. Erzurum July Solar Radiation Monthly Average of the Daily Distribution

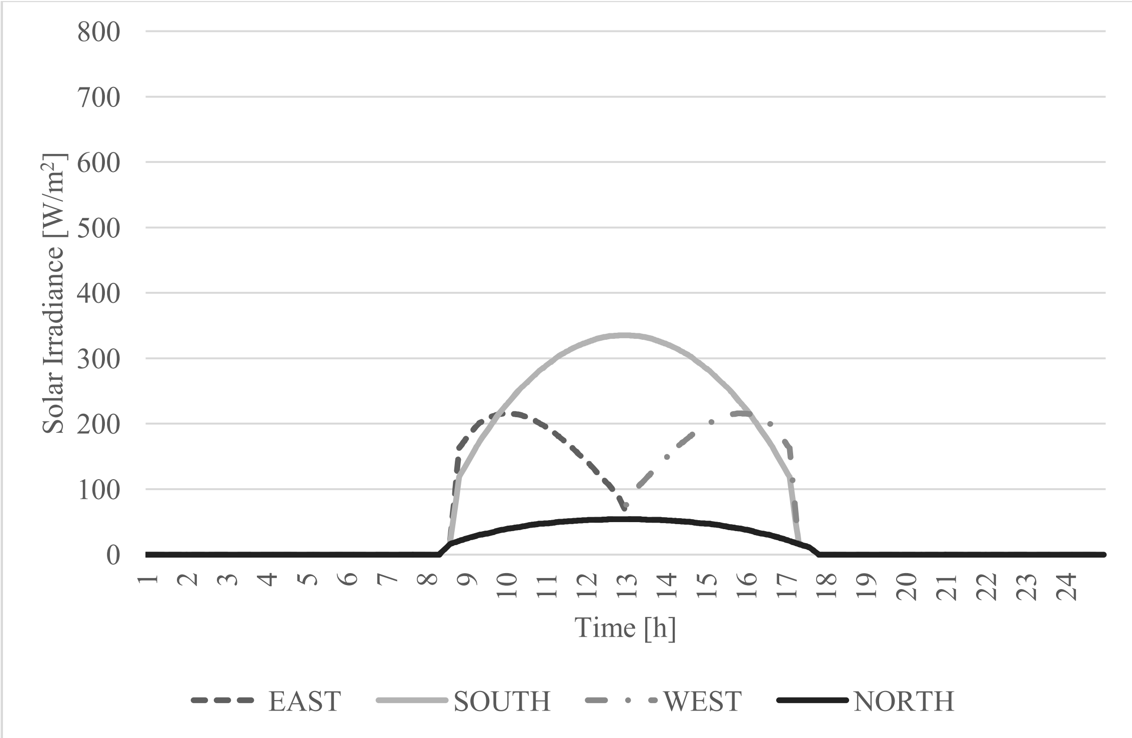

Figure D5. İstanbul January Solar Radiation Monthly Average of the Daily Distribution

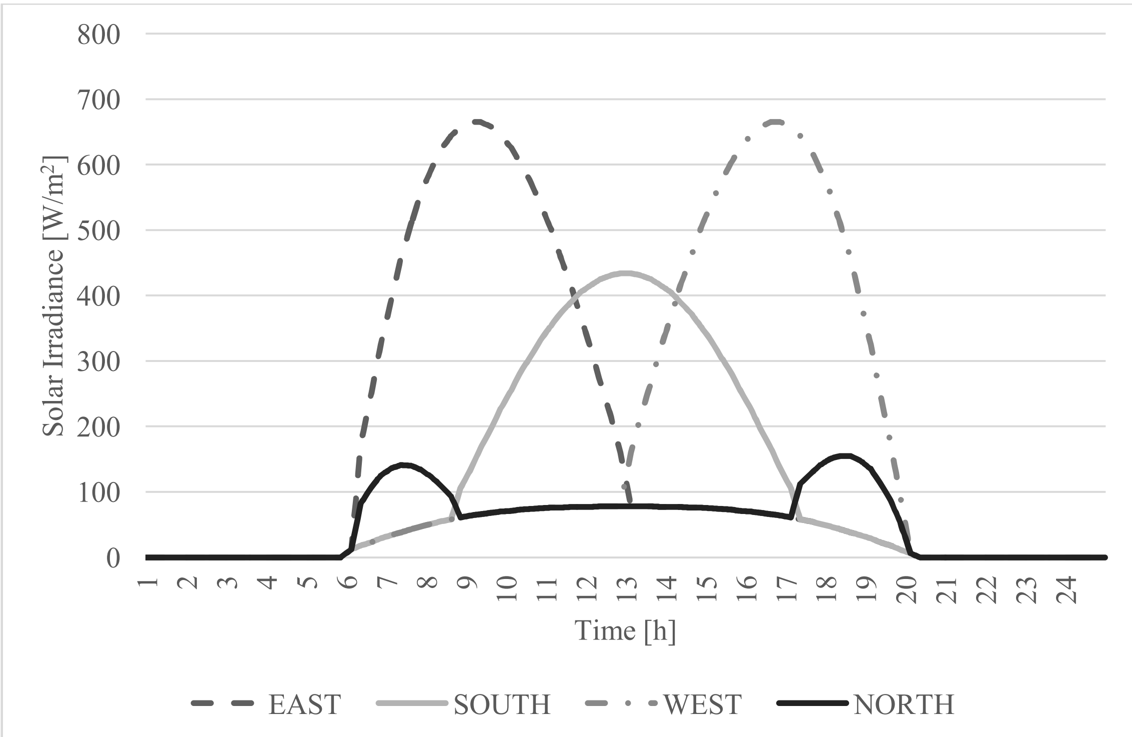

Figure D6. İstanbul July Solar Radiation Monthly Average of the Daily Distribution

APPENDIX E

MONTHLY AVERAGE OF THE DAILY DATA OF RELATIVE HUMIDITY AND TEMPERATURE

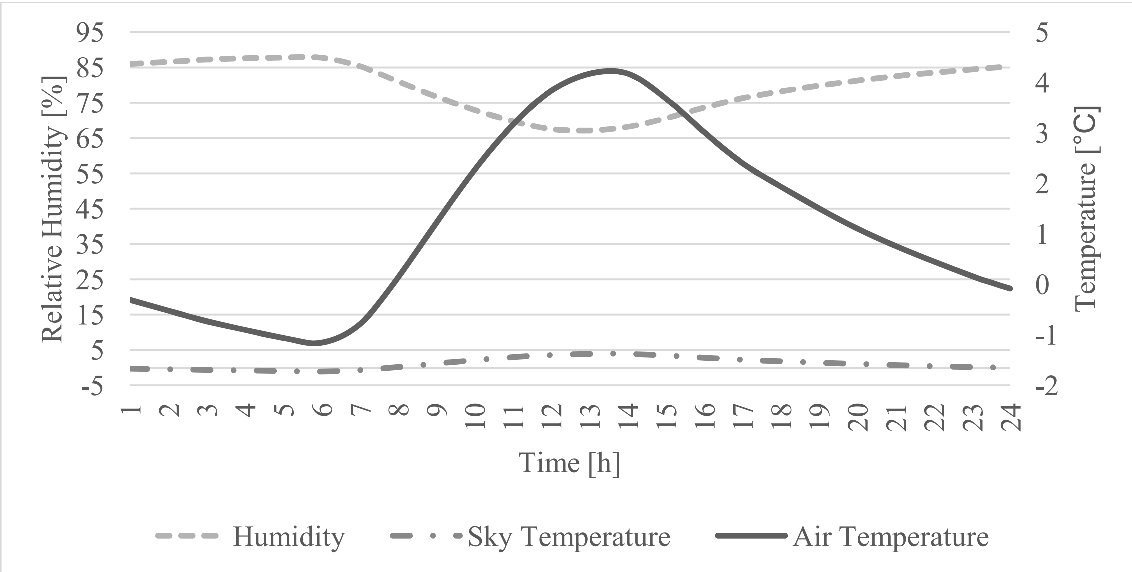

Figure E1. Sky Temperature and Air Temperature and Relative Humidity Versus Time of the Monthly Average of the Daily January Data in Ankara.

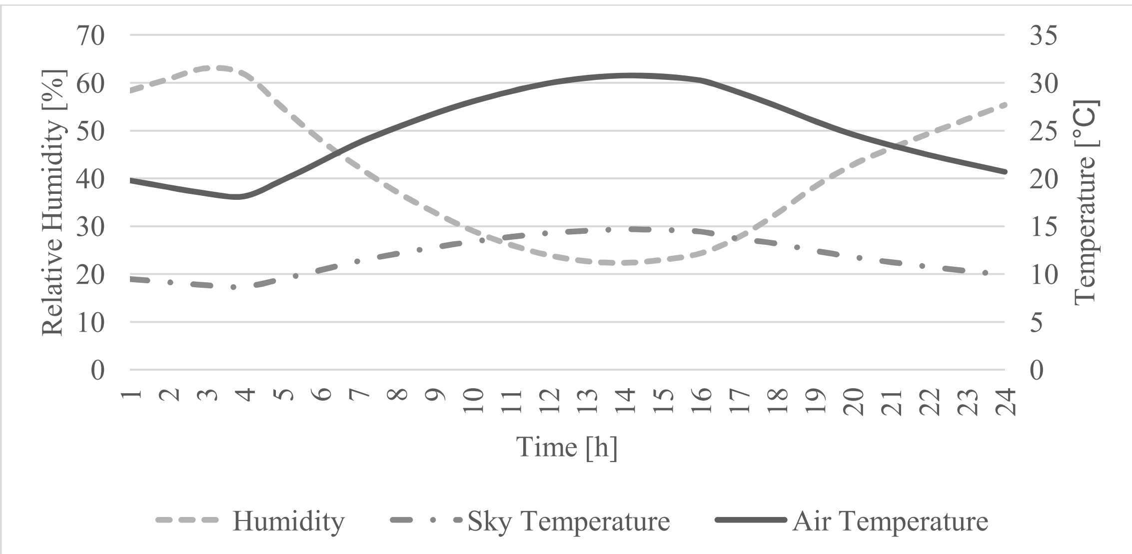

Figure E2. Sky Temperature and Air Temperature and Relative Humidity Versus Time of the Monthly Average of the Daily July Data in Ankara.

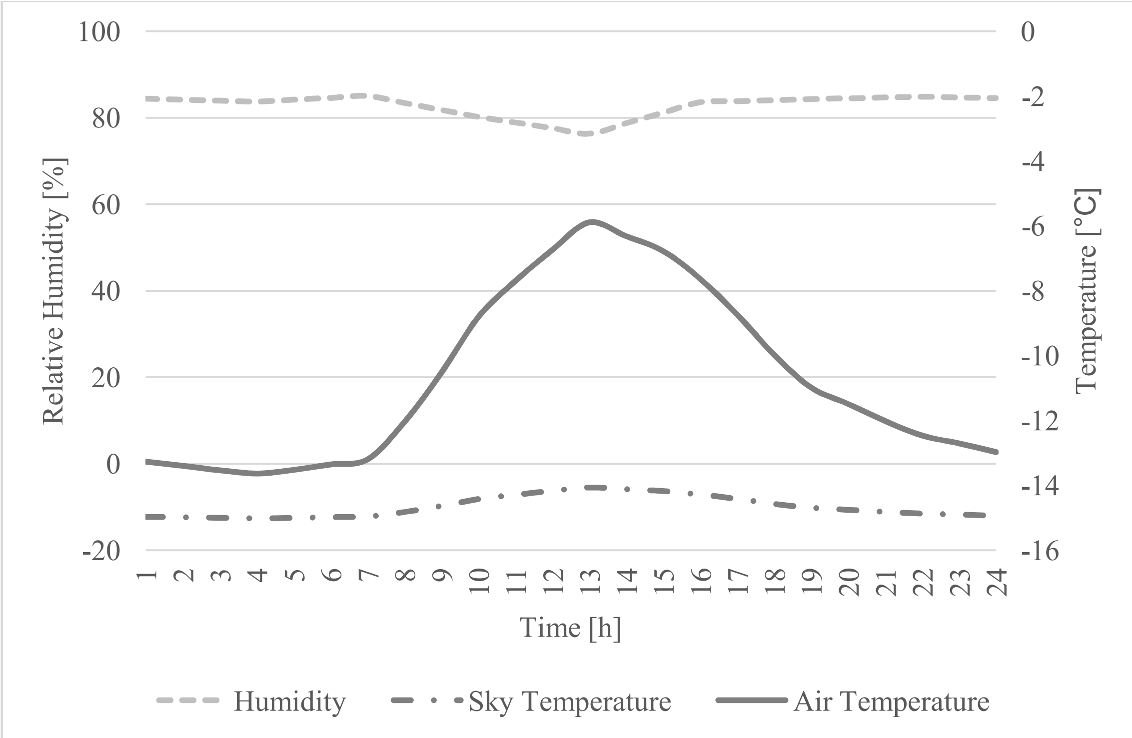

Figure E3. Sky Temperature and Air Temperature and Relative Humidity Versus Time of the Monthly Average of the Daily January Data in Erzurum.

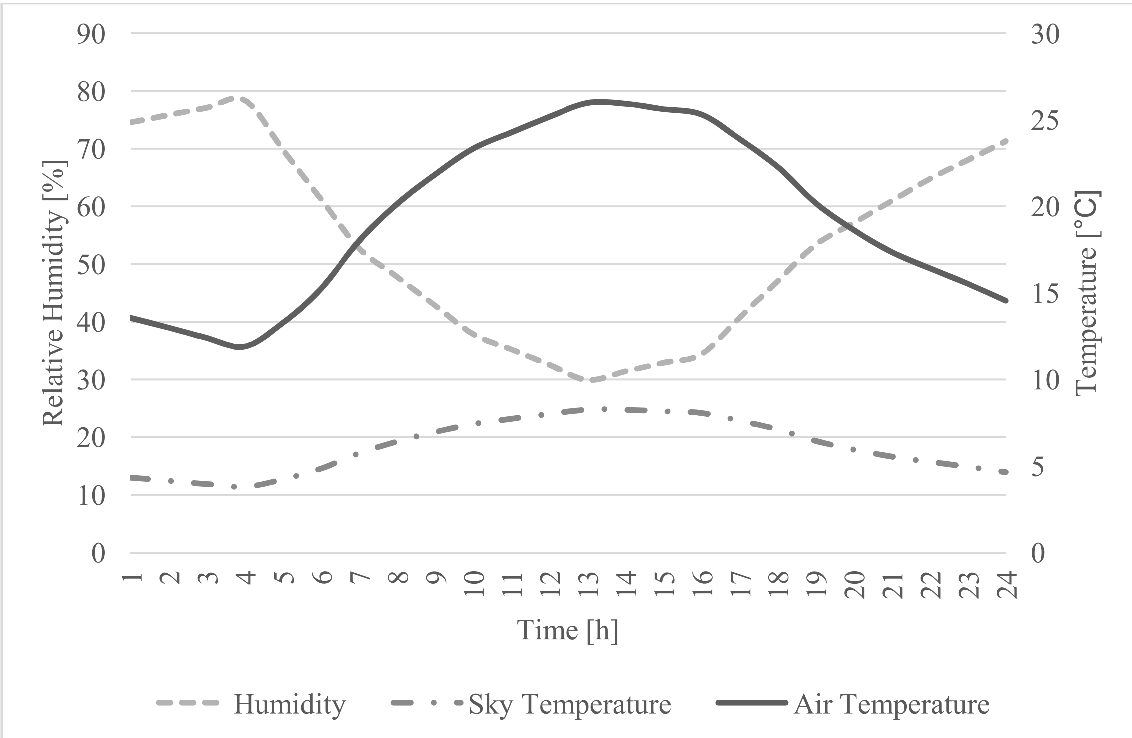

Figure E4. Sky Temperature and Air Temperature and Relative Humidity Versus Time of the Monthly Average of the Daily July Data in Erzurum.

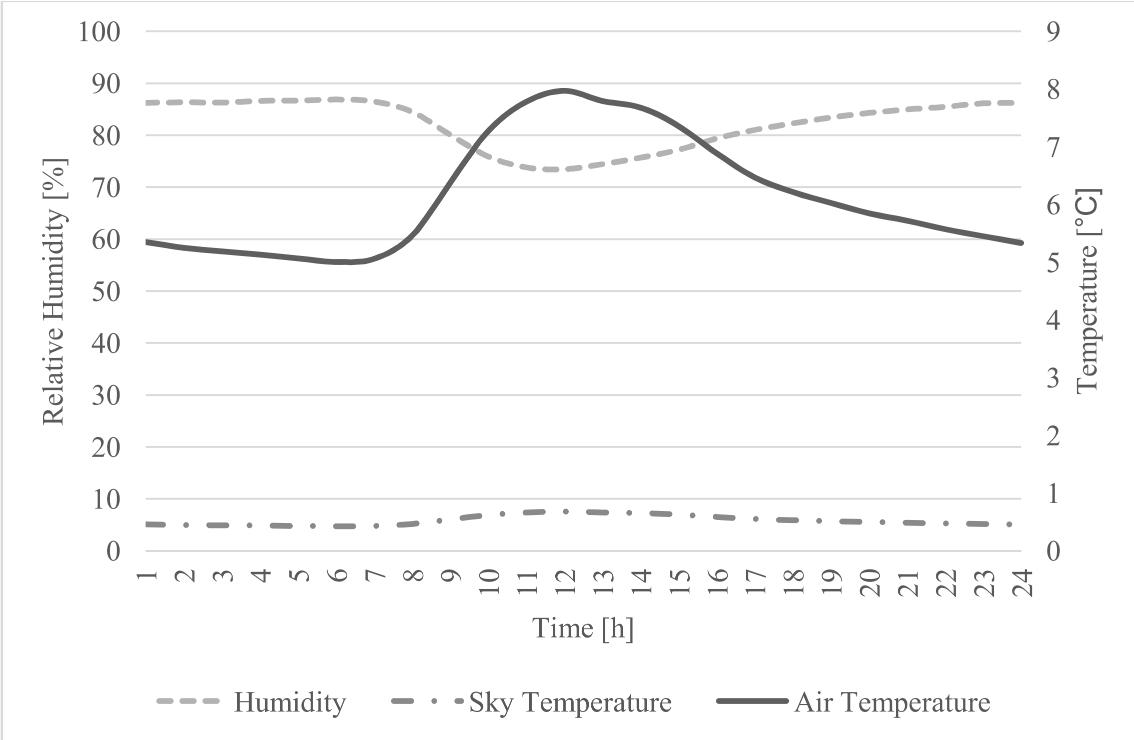

Figure E5. Sky Temperature and Air Temperature and Relative Humidity Versus Time of the Monthly Average of the Daily January Data in İstanbul.

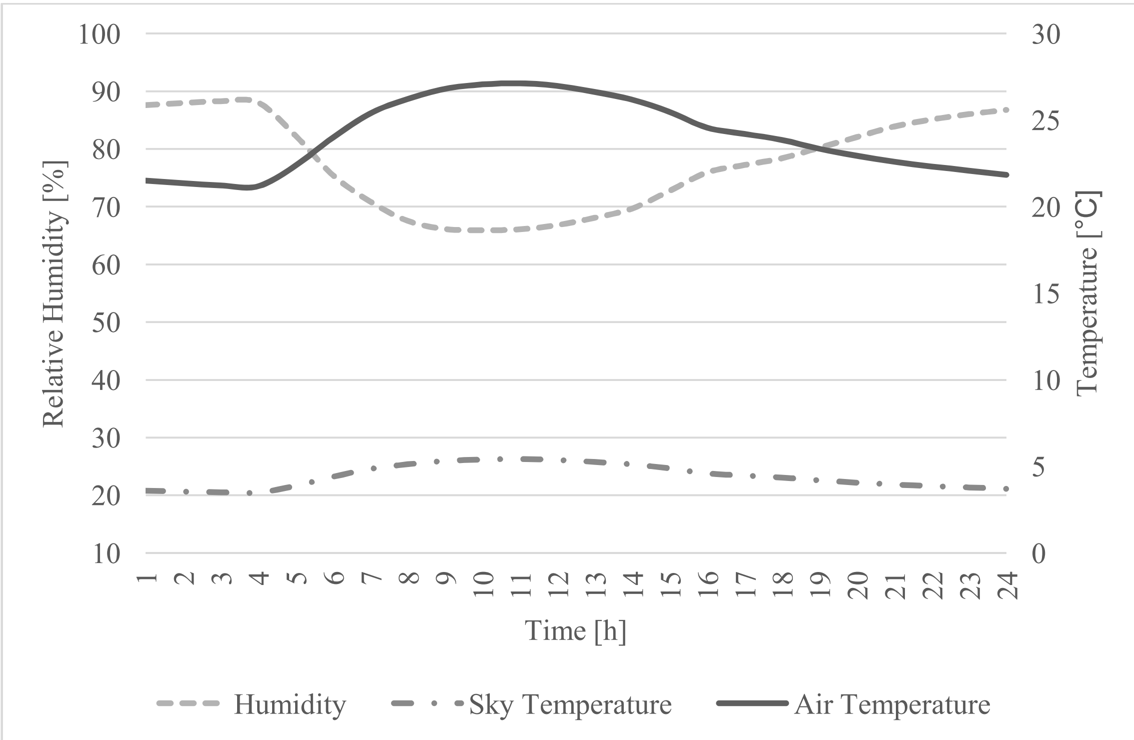

Figure E6. Sky Temperature and Air Temperature and Relative Humidity Versus Time of the Monthly Average of the daily July Data in İstanbul.

APPENDIX F

SANDWICH WALL TEMPERATURE DISTRIBUTION AT DIFFERENT TIMES OF THE DAY

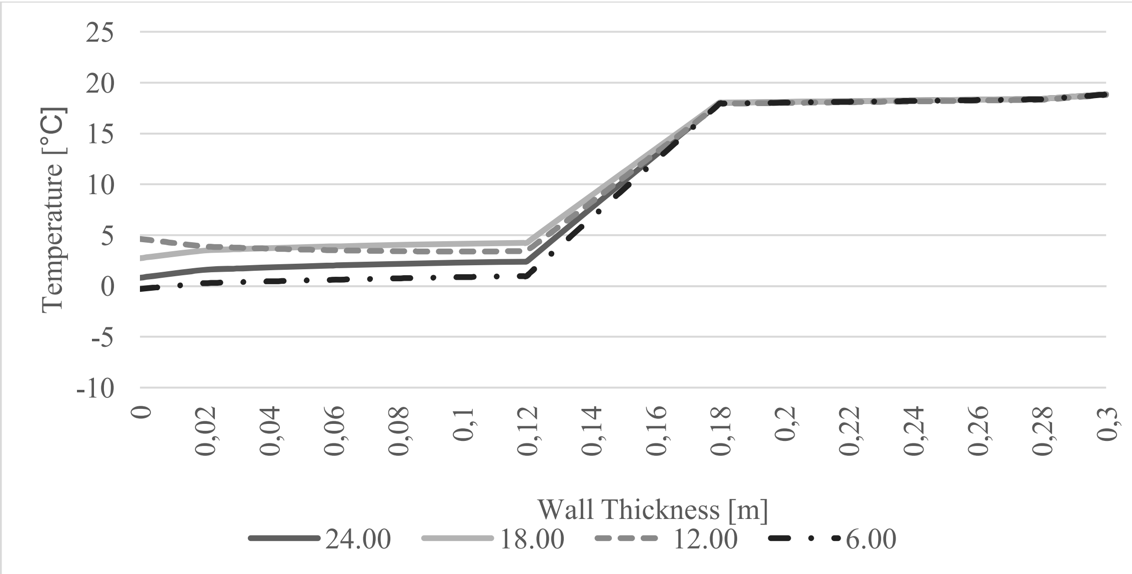

Figure F1. Sandwich Wall Temperature Distribution Across the Wall Thickness at Different Times of the Day for East Facing Wall in January in Ankara.

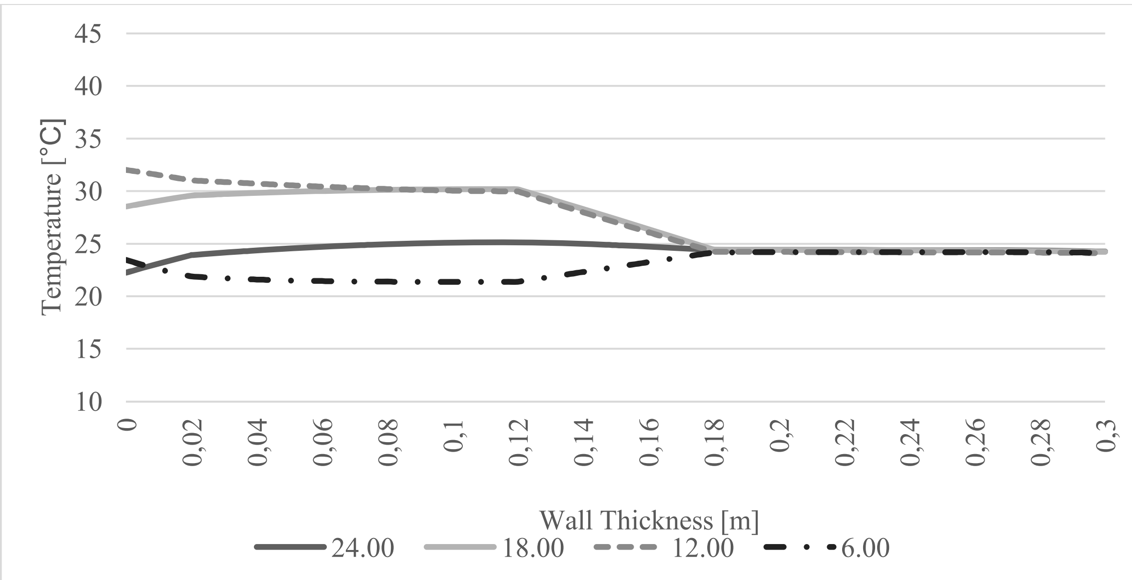

Figure F2. Sandwich Wall Temperature Distribution Across the Wall Thickness at Different Times of the Day for East Facing Wall in July in Ankara.

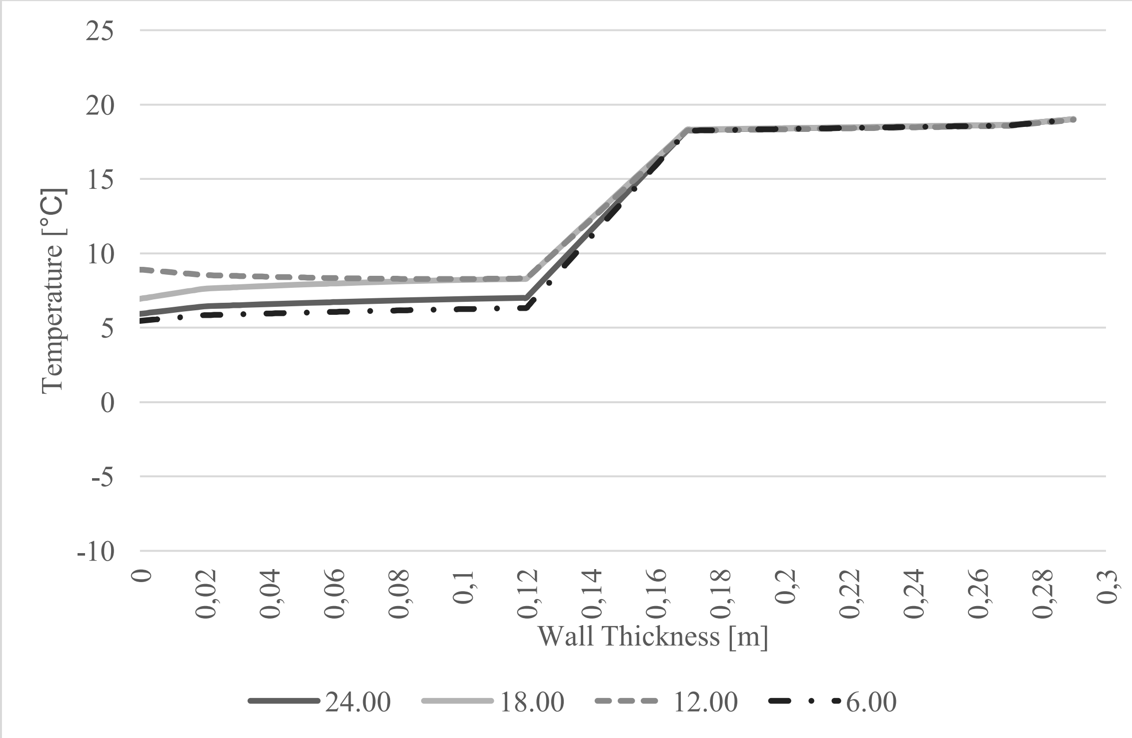

Figure F3. Sandwich Wall Temperature Distribution Across the Wall Thickness at Different Times of the Day for East Facing Wall in January in İstanbul.

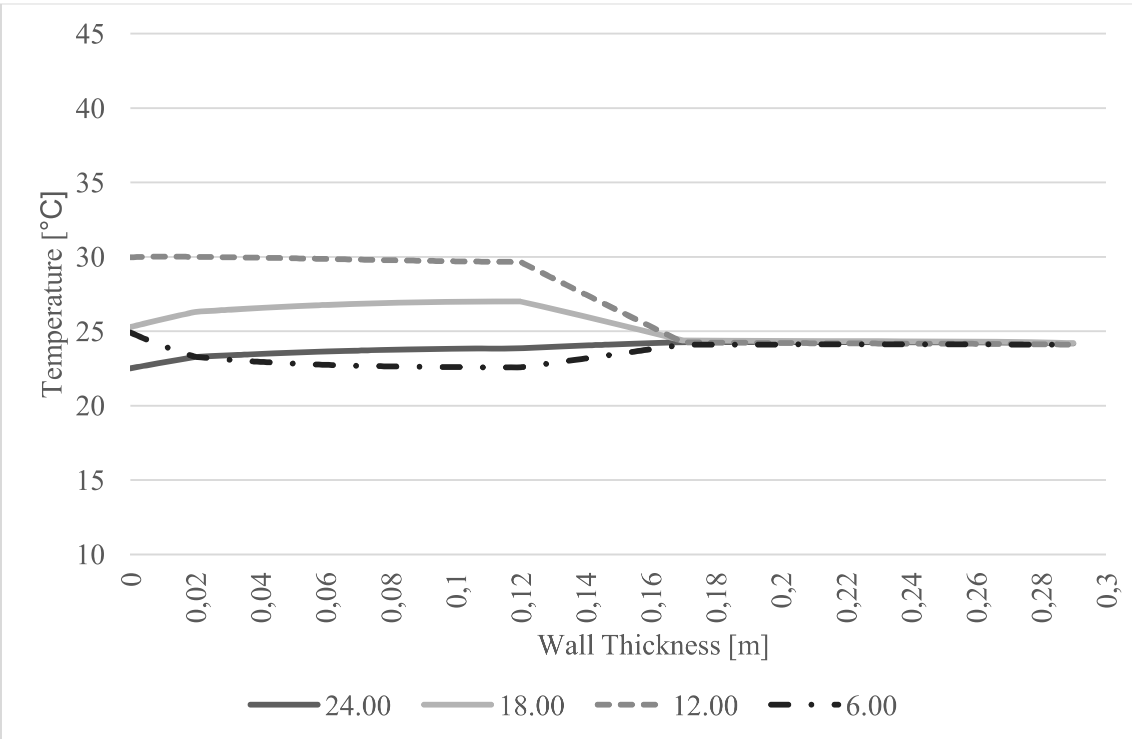

Figure F4. Sandwich Wall Temperature Distribution Across the Wall Thickness at Different Times of the Day for East Facing Wall in July in İstanbul.

APPENDIX G

HOURLY VARIATION OF INSIDE SURFACE HEAT FLUX OF SANDWICH WALL STRUCTURES

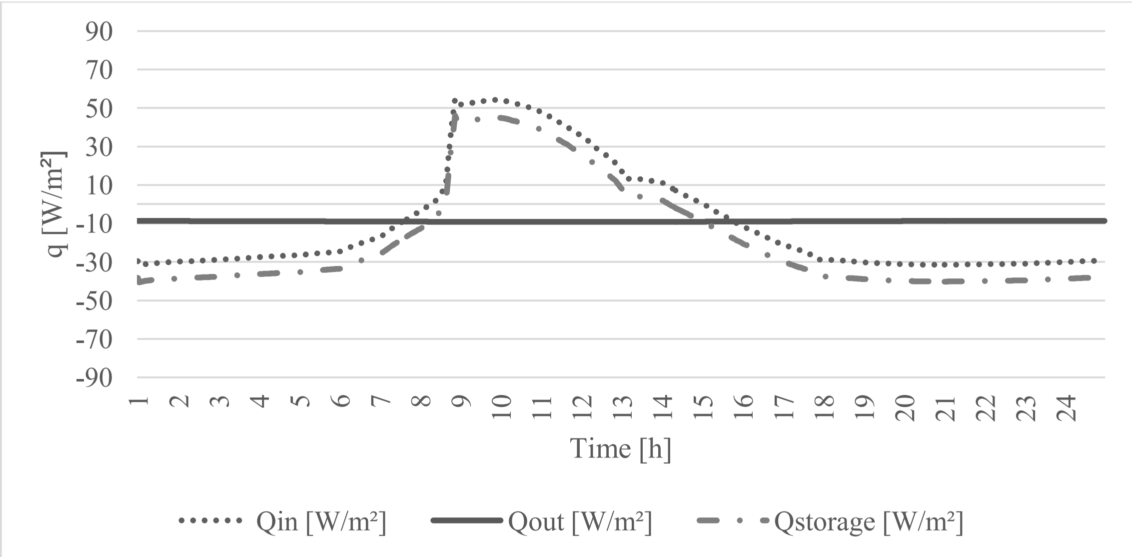

Figure G1. Hourly Variation of Inside Surface Heat Flux of Sandwich Wall Structures Under Optimal Insulation Conditions for January East Facing in Ankara.

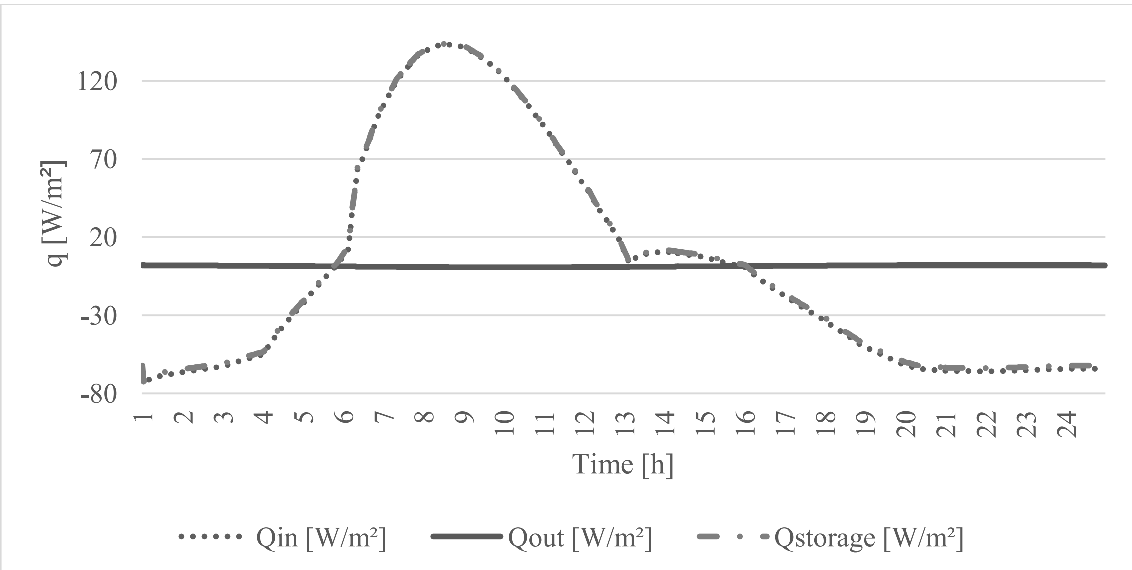

Figure G2. Hourly Variation of Inside Surface Heat Flux of Sandwich Wall Structures Under Optimal Insulation Conditions for July East Facing in Ankara.

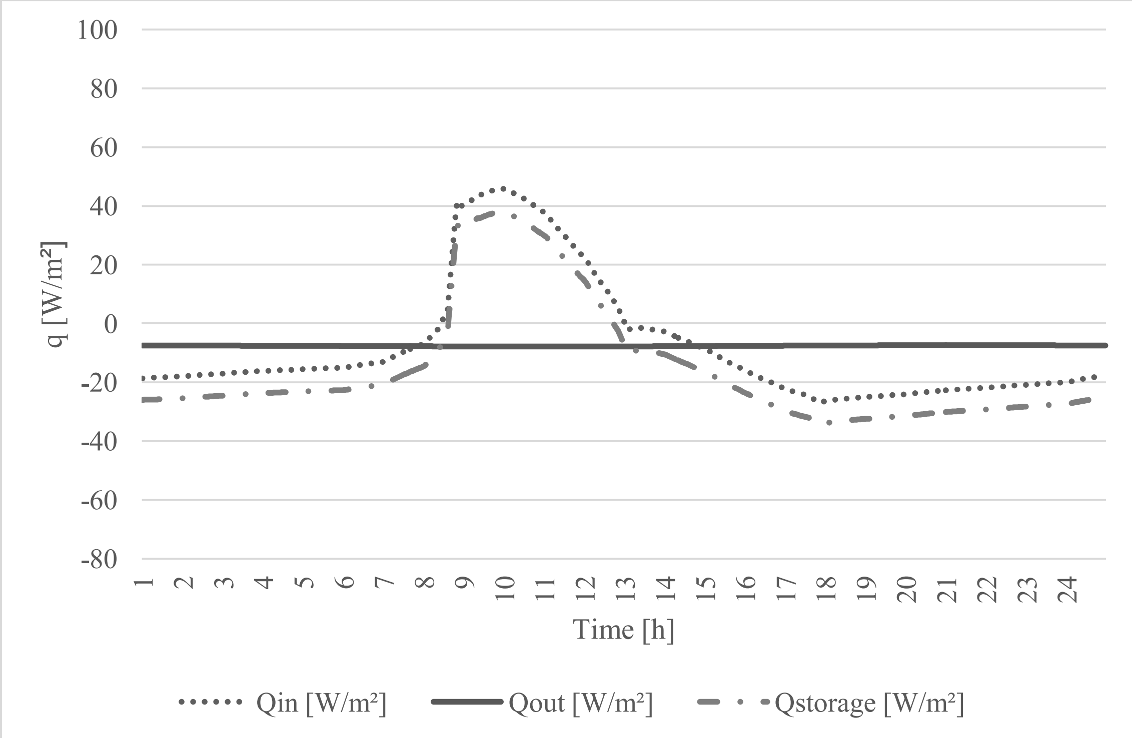

Figure G3. Hourly Variation of Inside Surface Heat Flux of Sandwich Wall Structures Under Optimal Insulation Conditions for January East Facing in İstanbul.

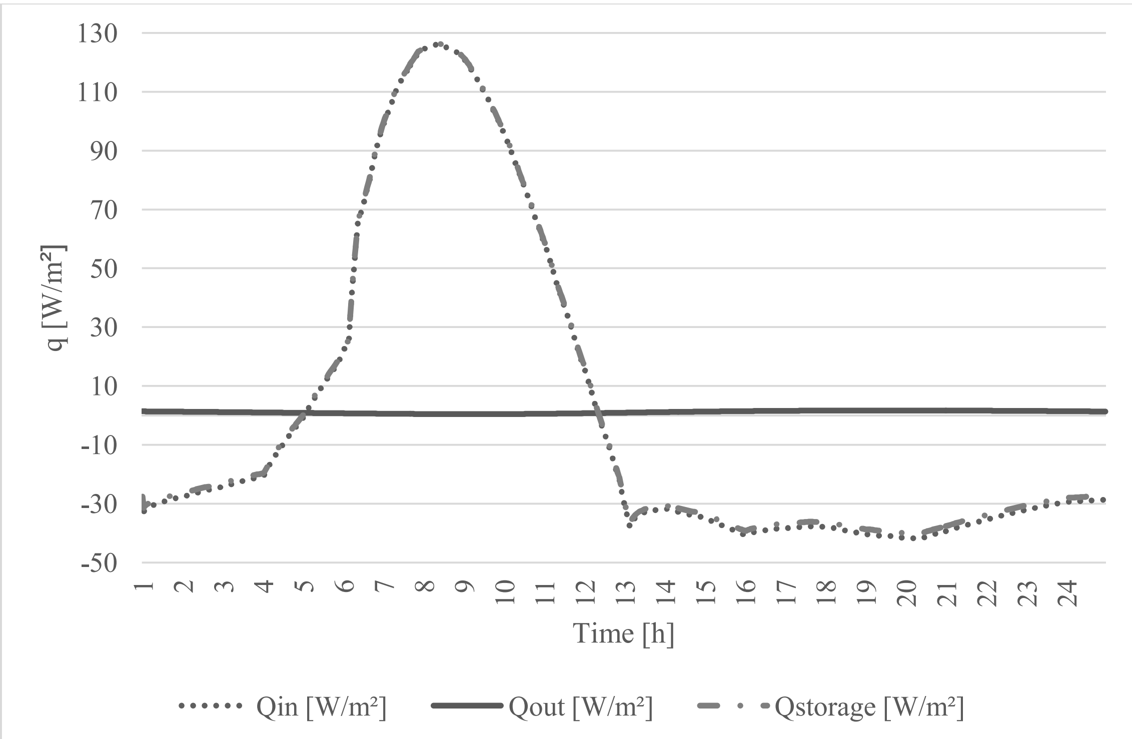

Figure G4. Hourly Variation of Inside Surface Heat Flux of Sandwich Wall Structures Under Optimal Insulation Conditions for July East Facing in İstanbul

APPENDIX H

UNINSULATED AND INSULATED WALL TYPES DAILY CONDUCTIVE HEAT FLOW RESULTS

Table H1. Uninsulated and Insulated Wall Types Daily Conductive Heat Flow Through a Uniform Plane Wall Comparison, Considering Wall Orientations Both Winter and Summer for Ankara.

ANKARA			Unisulated Wall (Wh/m².day)	Exterior Wall Insulation (Wh/m².day)	Interior Wall Insulation (Wh/m².day)	Sandwich Wall Insulation (Wh/m².day)
East	Winter	**20°C**	-1318.582	-215.496	-216.632	-213.494
	Summer	**24°C**	213.037	34.028	35.046	34.231
South	Winter	**20°C**	-1258.539	-206.699	-206.782	-203.819
	Summer	**24°C**	171.219	27.316	27.800	24.952
West	Winter	**20°C**	-1315.705	-216.069	-216.186	-213.068
	Summer	**24°C**	216.456	34.104	35.085	31.918
North	Winter	**20°C**	-1344.435	-220.749	-220.890	-217.683
	Summer	**24°C**	113.999	17.060	18.437	15.768
TS825	Winter	**20°C**	-1552.706	-240.233	-242.012	-238.275
	Summer	**24°C**	175.922	27.219	27.420	26.997

Table H2. Uninsulated and Insulated Wall Types Daily Conductive Heat Flow Through a Uniform Plane Wall Comparison, Considering Wall Orientations Both Winter and Summer for Erzurum.

ERZURUM			Unisulated Wall (Wh/m².day)	Exterior Wall Insulation (Wh/m².day)	Interior Wall Insulation (Wh/m².day)	Sandwich Wall Insulation (Wh/m².day)
East	Winter	**20°C**	-2178.583	-279.827	-278.680	-275.806
	Summer	**24°C**	-186.666	-39.908	-23.799	-23.377
South	Winter	**20°C**	-2128.690	-276.100	-272.288	-269.880
	Summer	**24°C**	-237.222	-34.308	-30.286	-28.782
West	Winter	**20°C**	-2175.107	-279.407	-278.127	-276.301
	Summer	**24°C**	-184.547	-39.362	-23.667	-23.496
North	Winter	**20°C**	-2198.702	-282.413	-281.267	-278.896
	Summer	**24°C**	-282.194	-42.668	-36.029	-33.489
TS825	Winter	**20°C**	-1942.990	-234.507	-235.860	-233.014
	Summer	**24°C**	-198.889	-24.005	-24.143	-23.852

Table H3. Uninsulated and Insulated Wall Types Daily Conductive Heat Flow Through a Uniform Plane Wall Comparison, Considering Wall Orientations Both Winter and Summer for İstanbul.

ISTANBUL			Unisulated Wall (Wh/m².day)	Exterior Wall Insulation (Wh/m².day)	Interior Wall Insulation (Wh/m².day)	Sandwich Wall Insulation (Wh/m².day)
East	Winter	**20°C**	-968.730	-184.795	-185.534	-182.150
	Summer	**24°C**	142.549	26.786	27.288	27.077
South	Winter	**20°C**	-914.957	-179.826	-175.261	-172.714
	Summer	**24°C**	111.062	20.618	21.233	21.029
West	Winter	**20°C**	-968.454	-185.552	-185.504	-182.152
	Summer	**24°C**	145.601	26.496	27.705	27.248
North	Winter	**20°C**	-991.618	-187.981	-189.922	-186.199
	Summer	**24°C**	48.501	9.068	9.304	9.247
TS825	Winter	**20°C**	-1242.076	-235.545	-237.581	-233.312
	Summer	**24°C**	65.372	12.397	12.504	12.280

APPENDIX I

UNINSULATED AND INSULATED WALL TYPES DAILY CONDUCTIVE HEAT FLOW INFERRED RESULTS COMPARISON WITH TS-825

Table I1. Uninsulated and Insulated Wall Types Daily Conductive Heat Flow Inferred Results Comparison With TS-825 Results Considering Wall Orientations Both Winter and Summer for Ankara.

$\frac{Q_{TS825} - Q_{calc}}{Q_{calc}}$		ANKARA	Unisulated Wall (Wh/m².day)	Exterior Wall Insulation (Wh/m².day)	Interior Wall Insulation (Wh/m².day)	Sandwich Wall Insulation (Wh/m².day)
East	Winter	**20°C**	0.151	0.103	0.105	0.104
	Summer	**24°C**	-0.211	-0.250	-0.278	-0.268
South	Winter	**20°C**	0.189	0.140	0.146	0.145
	Summer	**24°C**	0.027	-0.004	-0.014	0.076
West	Winter	**20°C**	0.153	0.101	0.107	0.106
	Summer	**24°C**	-0.230	-0.253	-0.280	-0.182
North	Winter	**20°C**	0.134	0.081	0.087	0.086
	Summer	**24°C**	0.352	0.373	0.328	0.416

Table I2. Uninsulated and Insulated Wall Types Daily Conductive Heat Flow Inferred Results Comparison With TS-825 Results Considering Wall Orientations Both Winter and Summer for Erzurum.

$\frac{Q_{TS825} - Q_{calc}}{Q_{calc}}$		ERZURUM	Unisulated Wall (Wh/m².day)	Exterior Wall Insulation (Wh/m².day)	Interior Wall Insulation (Wh/m².day)	Sandwich Wall Insulation (Wh/m².day)
East	Winter	**20°C**	-0.121	-0.193	-0.182	-0.184
	Summer	**24°C**	0.061	-0.663	0.014	0.020
South	Winter	**20°C**	-0.096	-0.177	-0.154	-0.158
	Summer	**24°C**	-0.193	-0.429	-0.254	-0.207
West	Winter	**20°C**	-0.119	-0.191	-0.179	-0.186
	Summer	**24°C**	0.072	-0.640	0.020	0.015
North	Winter	**20°C**	-0.132	-0.204	-0.193	-0.197
	Summer	**24°C**	-0.419	-0.777	-0.492	-0.404

Table I3. Uninsulated and Insulated Wall Types Daily Conductive Heat Flow Inferred Results Comparison With TS-825 Results Considering Wall Orientations Both Winter and Summer for İstanbul.

$\frac{Q_{TS825} - Q_{calc}}{Q_{calc}}$		ISTANBUL	Unisulated Wall (Wh/m².day)	Exterior Wall Insulation (Wh/m².day)	Interior Wall Insulation (Wh/m².day)	Sandwich Wall Insulation (Wh/m².day)
East	Winter	**20°C**	0.220	0.215	0.219	0.219
	Summer	**24°C**	-1.181	-1.161	-1.182	-1.205
South	Winter	**20°C**	0.263	0.237	0.262	0.260
	Summer	**24°C**	-0.699	-0.663	-0.698	-0.713
West	Winter	**20°C**	0.220	0.212	0.219	0.219
	Summer	**24°C**	-1.227	-1.137	-1.216	-1.219
North	Winter	**20°C**	0.202	0.202	0.201	0.202
	Summer	**24°C**	0.258	0.269	0.256	0.247