Energy and Economic Analyses of Natural Gas Heating Systems

Cenker Aktemur

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Approval of the Institute of Graduate Studies and Research

Prof. Dr. Mustafa Tümer
Director

I certify that this thesis satisfies the requirements as a thesis for the degree of Master of Science in Mechanical Engineering.

Assoc. Prof. Dr. Hasan Hacışevki
Chair, Department of Mechanical Engineering

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

Prof. Dr. Uğur Atikol
Supervisor

Examining Committee

1. Prof. Dr. Uğur Atikol
2. Prof. Dr. Fuat Egelioğlu
3. Asst. Prof. Dr. Murat Özdenefe

ABSTRACT

An immense amount of the energy consumed in residential buildings is used for heating purposes to ensure the thermal comfort of human beings. The daily average outdoor air temperature plays an important role in determining energy use for heating. Therefore, the climatic conditions in different regions considerably affect the energy needs for heating, and accordingly, fuel consumption. The method used during this study is heating degree-day (HDD) approach, which has been utilized in many buildings for energy analysis. Before calculating the HDD values, the total heat loss of a house on the ground floor of an insulated five-storey residential building was determined. This information was used toward this study's main aim, to investigate the yearly heating energy requirements and fuel consumption for natural gas and air-source heat pump heating systems with the utilization of single, double, and triple-glazed windows. All calculations were carried out with different base temperatures to calculate HDD values at the İzmit/Kocaeli Meteorology Station in Turkey, so that the carbon dioxide emissions resulting from these heating systems could be identified. Ultimately, heating systems were compared in terms of economic feasibility utilizing the life-cycle cost analysis (LCCA) method. Based on HDD values with a 15^{o}C base temperature, yearly fuel consumption and carbon dioxide emissions for natural gas heating were estimated to be approximately 15180, 13225, 11998 kWh, and 3552, 3095, 2808 kg CO_2 for single, double, and triple-glazed windows, respectively. Furthermore, yearly primary fuel consumptions and carbon dioxide emissions for a heat pump were estimated to be 3441, 2998, 2720 kWh, and 1218, 1061, 963 kg CO_2 per year for single, double, and triple-glazed windows, respectively. Considering the installation cost of a heat pump of 13,500 ₺, it was predicted for a newly built house that the savings-to-investment ratio (SIR) would be 1.5. For an existing house with installed natural gas heating system, upgrading to heat pump system could not be feasible. Additionally, economic feasibility indicators, such as net present value (NPV), internal rate of return (IRR), and simple payback (years) were estimated by using LCCA method.

Keywords: Energy analysis, heating degree-day, heating energy requirement, fuel consumption, carbon emission, economic analysis, Turkey.

ÖZ

Konutlarda tüketilen enerjinin büyük miktarı, insanoğlunun ısıl konforunu sağlamak için ısıtma amaçlı kullanılır. Günlük ortalama dış hava sıcaklığı, ısıtma için enerji kullanımının belirlenmesinde önemli bir rol oynamaktadır. Bu nedenle, farklı bölgelerdeki iklim koşulları, ısıtma için enerji ihtiyacını ve dolayısıyla yakıt tüketimini önemli ölçüde etkiler. Bu çalışma sırasında kullanılan yöntem, birçok binalarda enerji analizi için kullanılan ısıtma derece gün (HDD) yaklaşımıdır. HDD değerlerini hesaplamadan önce, yalıtılmış beş katlı bir konutun zemin katındaki bir evin toplam ısı kaybı tespit edilmiştir. Bu bilgi, doğal gaz ve hava kaynaklı ısı pompası ısıtma sistemleri için yıllık, tekli, çiftli ve üçlü camlı pencerelerin yıllık ısıtma enerjisi gereksinimlerini ve yakıt tüketimlerini araştırmak için bu çalışmanın temel amacına yönelik olarak kullanılmıştır. Bu ısıtma sistemlerinden kaynaklanan karbon dioksit emisyonlarının tespit edilebilmesi için tüm hesaplamalar, İzmit / Kocaeli Meteoroloji İstasyonunda HDD değerlerini hesaplamak için farklı taban sıcaklıklarıyla gerçekleştirildi. Sonuç olarak, ısıtma sistemleri, yaşam döngüsü maliyet analizi (LCCA) yöntemini kullanarak ekonomik fizibilite açısından karşılaştırılmıştır. 15^{o}C taban sıcaklığındaki HDD değerlerine dayanarak, doğal gaz ısıtması için yıllık yakıt tüketimi ve karbondioksit emisyonlarının, tek, çift ve üçlü camlar için yaklaşık 15180, 13225, 11998 kWh ve 3552, 3095, 2808 kg CO_2 olduğu tahmin edilmiştir. Ayrıca, bir ısı pompası için yıllık birincil yakıt tüketimleri ve karbon dioksit emisyonlarının sırasıyla, tek, çift ve üçlü camlar için 3441, 2998, 2720 kWh ve 1218, 1061, 963 kg CO_2 olduğu tahmin edilmiştir. 13,500 ₺'lik bir ısı pompasının kurulum maliyetini göz önüne alarak, yeni inşa edilen bir ev için tasarruf-yatırım oranı (SIR) 1.5 olacağı öngörülmüştür. Kurulu doğalgaz ısıtma sistemli mevcut bir ev için ısı pompası sistemine yükseltme ekonomik olarak mümkün olamazdı. Buna ek olarak, net bugünkü değer (NPV), iç verim oranı (IRR) ve basit geri ödeme (yıllar) gibi ekonomik fizibilite göstergeleri, LCCA yöntemi kullanılarak tahmin edilmiştir.

Anahtar Kelimeler: Enerji analizi, ısıtma derecesi, ısıtma enerjisi ihtiyacı, yakıt tüketimi, karbon emisyonu, ekonomik analiz, Türkiye.

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DEDICATION

To my family for their never ending ongoing

support and forbearance

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LIST OF SYMBOLS

A	Surface Area (m^2)
c_p	Specific Heat Capacity of Air (kJ/kg°C)
D	Yearly Energy Demand (J)
FC	Yearly Fuel Consumption (m^3, kWh)
I	Air Exchange Rate for Ventilation (h^{-1})
k	Thermal Conductivity of Material (W/m°C)
n	Number of Residences
N	Air Exchange Rate for Infiltration (h^{-1})
Q	Total Heat Loss (W)
T	Air Temperature (ºC)
U	Overall Heat transfer Coefficient [W/(m^2·ºC)]

Greek symbol

η	Heating System Efficiency (%)
ρ	Density of Air (kg/m^3)

Subscript

b	Base
c	City
i	Infiltration
max	Maximum
min	Minumum
o	Outside
t	Transmission
v	Ventilation

LIST OF ABBREVIATIONS

COP	Coefficient of Performance
DD	Degree-Day (^oC-day)
EF	Energy Factor
HDD	Heating Degree-Day (^oC-day)
IRR	Internal Rate of Return
LCCA	Life-Cycle Cost Analysis
LCCI	Life-Cycle Cost Investment
LHV	Lower Heating Value (J/m^3, J/kWh)
NPV	Net Present Value
PV	Present Value
SIR	Savings-to-Investment Ratio
SPP	Simple Payback Period (years)
XPS	Extruded Polystyrene Foam

Chapter 1

INTRODUCTION

1.1 Background

Energy is one of humanity’s most basic needs and is the lifeblood of developed countries and industrial societies. Populations in all industrialised nations rely on energy to meet their daily needs, with the burning of fossil fuels as the primary energy source for heating, cooling, lighting and cooking. However, with the growing world population and increasing industrialisation, energy demands are rapidly escalating. The increased reliance on energy for basic daily needs has led to an increase in costs and an associated cost impact on the environment; as a result, studies that focus on cutting unnecessary costs have been gaining prominence [1].

Turkey uses different types of renewable and non-renewable energy sources. When energy use is assessed, most of Turkey’s energy requirements are met by fossil fuels. According to the Ministry of Energy and Natural Resources' national climate change action plan [2] in 2013, Turkey’s energy sources comprise 31% coal, 30.9% natural gas, 28.8% petroleum, 4.4% bio-fuel, 2.9% hydroelectric, 1.2% geothermal, 0.4% solar energy and 0.12% wind energy sources.

Natural gas has become irreplaceable and is an increasingly used source of energy in recent years. The demand for natural gas is increasing considerably for residential heating systems in cold seasons. Between the months of December and March (peak time), approximately 70% of annual natural gas consumption occurs; however, in the warmer months, consumption drops to negligible levels [3].

Energy consumption can be generally examined in four major sectors, namely industry, building, transportation and agriculture. In the majority of countries, energy consumption in residential buildings is a substantial proportion of the country's total energy consumption. Indeed, in Turkey, around 40% of energy usage in residential buildings is used for heating; therefore, it is vital that the heating of buildings is studied in order to identify ways in which this cost can be reduced [4].

1.2 Structure of Natural gas

Natural gas is a fossil-derived gas. It consists of large quantities of methane gas, which is found below the ground like petroleum in nature [5]. There are diverse explanations regarding the origin of hydrocarbon, which is a fossil fuel. Most commonly, it is believed that natural gas comes into existence as a result of changes in the organic bacteria settling within the sediment at the bottoms of seas and lakes over millions of years. Many investigations conducted in the natural gas field have found that methane is an essential chemical composition in natural gas, as shown in Table 1. Others include methane, ethane, propane, carbon dioxide, oxygen, nitrogen and hydrogen sulfide.

Table 1: Typical Compositions of Natural Gas by Mole [6]

Product	Structure	Composition range
Methane	CH_4	70 - 90%
Ethane	C_2H_6	0 - 20%
Propane	C_3H_8	
Butane	C_4H_{10}	
Carbon Dioxide	CO_2	0 - 8%
Oxygen	O_2	0 - 0.2%
Nitrogen	N_2	0 - 5%
Hydrogen Sulphide	H_2S	0 - 5%
Rare Gases	A, He, Ne, Xe	Trace

Natural gas is one of the cleanest fuels among non-renewable energy sources because it has an efficiency ranging from 0.85 to 0.95. Therefore, it has a leading role in many parts of the world. It contains paraffin, carbon and a mixture of hydrogen in a gaseous state; the percentage of these hydrocarbons in natural gas varies depending on its source. It mainly consists of methane (CH_4) and, to a lesser extent, etan (C_2H_6), butane (C_4H_{10}) and propane (C_3H_8). In addition, nitrogen (N_2), carbon dioxide (CO_2), hydrogen sulfide (H_2S) and helium (He) are all found in natural gas. Natural gas, which exists in the gaseous state at room temperature and under atmospheric pressure, has many advantageous chemical properties. For example, it is a relatively non-hazardous gas and does not have overly adverse effects in case of exposure through inhalation [7].

1.3 Advantages of Natural Gas

The advantageous and attractive characteristics of natural gas are summarised below [8,9].

- It is a cheap heating source compared to other fuels. Unit prices of fuels are 6.8 ₺/kg for LPG, 1.08 ₺/m^3 for natural gas and 0.94 ₺/kg for coal.

- It is a lighter gas than air. Therefore, it tends to rise in the air. If any gas leaks occur, the gas can easily be removed through ventilation pipes or culverts.
- It is a dry gas that does not contain water vapour. Teflon must be employed as a special sealing material for pipe joints due to the dryness of natural gas.
- It does not pollute the environment. Emissions that are harmful to the environment, such as ash, unburned hydrocarbons and sulphur compounds, do not occur.
- It is not explosive. It must have a value between 5 and 15% concentration in the air in order to gain explosive properties. If it falls below these percents, there will be no risk of explosion.

1.4 Thesis Objectives

The quantity of fuel required for heating residential buildings, or even an entire area, city, or region, can be estimated with a fair degree of precision based on the average daily air temperature in the external environment. To this end, the heating degree-day (HDD) technique is a popular tool of energy analysis. The present study aims to use the records of average outside temperature from the İzmit meteorological station in Kocaeli to determine the yearly heating energy requirements associated with three types of glass (i.e. single, double and triple) at varying base temperature. Subsequently, fuel consumption is investigated and compared based on natural gas and air-source heat pump heating systems. Once the amount of fuel consumed by the different heating systems is determined, the levels of carbon dioxide emitted into the atmosphere are measured. Finally, the heating systems are investigated from an economical perspective.

1.5 Organization of the Thesis

This thesis comprises of six chapters. A concise outline of the remaining chapters is as follow:

The second chapter covers a short history of natural gas and studies pertaining to energy and economic analyses carried out by researchers.

The third chapter describes the methodology to determine total heat loss, heating energy requirements, and fuel consumptions. For this reason, a house on the ground floor is selected in Kocaeli province of Turkey in order to determine the heat losses due to ventilation, infiltration and transmission by taking into consideration design conditions such as indoor and outdoor temperatures, U-values of the wall, window and floor.

The fourth chapter is devoted to analyze heating degree-days (HDD) at various base temperatures for İzmit/Kocaeli, which is located on the western coast of Turkey (latitude 40°47' N, longitude 29°58 E). Then, the annual fuel consumption for natural gas and air-source heat pump heating systems are forecasted based on the total heat loss of a house in ground floor, after the heating energy requirement is determined.

The fifth chapter draws attention to the economical aspects of the problem by concentrating on the feasibility of natural gas-based heating system compared to air-source heat pump heating systems considering their life expectancy.

The sixth chapter is allocated for conclusions and recommendations that covers all the aspects of the thesis.

Chapter 2

LITERATURE REVIEW

2.1 A Brief Historical Review on Natural Gas

Energy is an ongoing issue for the social and economic development of countries around the world, as it also deals with social welfare and environmental issues. Global population growth is increasing, which is associated with efforts to improve living standards, especially in light of energy demand and consumption growth. It is noteworthy to obtain energy from continuous, cheap, reliable and clean sources and to utilise it efficiently [10].

The history of natural gas, which constitutes one of the most significant energy sources of our era, dates back hundreds of years. The statement of the “Sacred Fire” has been used throughout the history of humanity. For the first time, natural gas was utilised as an energy source by the Chinese for the salt-drying process. Subsequently, they transported natural gas to other places by means of hollowed bamboos [11]. Thus, natural gas began to spread rapidly in a consistent manner. It varies depending on the usage adopted by the majority of the population and has gradually expanded over the course of many years across large parts of the world, particularly in the European and Eurasian region in which Turkey is located (see Figure 1). The fact that natural gas is a clean fuel, portable and easy to use can be regarded as evidence among the reasons pertaining to the continuous increase in consumption in this region.

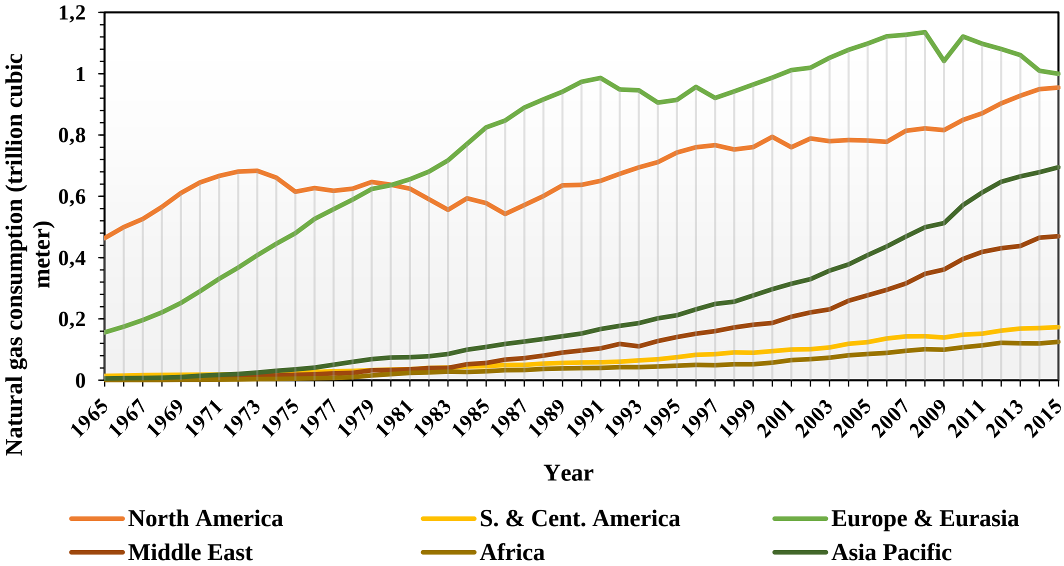

Figure 1: Natural Gas Consumptions vs. Years by Regions [12]

2.2 Studies Conducted on Energy and Economic Analysis

The first work in the sense of degrees-days (DDs) was conducted in the 1700's and studies in this direction accelerated in the 20th century. As time goes by, the DD technique has been further developed and been reliably utilized for many purposes by researchers [13].

The heating degree-day (HDD) method was employed by Sarak and Satman (2003) [14] in estimating the total natural gas consumption in Turkey resulting from heating buildings. Using population data, daily temperature records for major cities and the settlement records of buildings, it was estimated that a maximum of approximately 14.9 Gm^3 of natural gas would be required in 2023.

Durmayaz et al. (2000) [15] carried out a case study on the calculation of energy demand and fuel consumption of Istanbul, which is located in the second degree-day zone in Turkey, taking into account the degree-hour approach. Natural gas consumption is calculated taking into account various glazing type (i.e. single and double glass) and surface area (GAP), and air infiltration rate (I), and the number of people (n) living in a prototype building. A prototype building was created to carry out the studies and it is estimated that between 20-60 people lived in the apartment apartment building. They clarified that this approach can effortlessly be employed in comparable applications for any a part of the world.

In order to calculate the quantity of fuel requirement to heat the buildings, Dagsoz (1995) [16] employed the heating degree day (HDD) method. The 10-year average temperature values for 67 Turkish provinces were used to determine the base temperatures of 12 and 18°C.

Arisoy et al. (1999) [17] calculated the natural gas fuel consumption for 6 stations in 4 city centers using DD method. In their study, hourly temperature data were used and it was concluded that a significant amount of fuel savings will be achieved if the heating requirement provided by combi system is turned off for 6 hours at night.

Satman and Altun (1991) [18] prepared a general heating degree day (HDD) map for 75 meteorological stations in Turkey to calculate HDD values using the monthly mean air temperature data from at least 30 years. They also tried to determine the natural gas consumption potential in residential heating using HDD values.

Aras and Aras (2005) [19] introduced autoregressive time series models developed to estimate the consumption of natural gas used in residential buildings during the heating period. They investigated the dynamic relationship between natural gas consumption and weather changes expressed in time and degree-days and analysed the effect of various economic indicators – including natural gas price, dollar selling rate and consumer price index – on natural gas usage. As a result, economic indicators for consumers, as well as time and weather variables, were found to play a decisive role in the natural gas demand of residential buildings.

Serdar (2006) [20] conducted a study to determine the annual heating energy requirement for building models employing four different architectural design features in the Bursa province of Turkey. For these calculations, 14 years of meteorological data were obtained from State Meteorology Affairs. The DD method was employed for the energy analysis. Heat losses were calculated for four different building models using 14-year external air temperature data. Then, the fuel consumption of natural gas as a fuel was calculated after determining the heating energy requirement.

Serpen ve Palabıyık (2006) [21] carried out a research using four different heating systems (natural gas, LPG, geothermal heat pump and solar energy-assisted natural gas) used in residential heating to determine the amount of heat required by a residence. These four heating systems were investigated for the heating of a 240 m^2 residence on the Black Sea coast of Istanbul. For each heating system, the initial investment cost, fuel cost and operating costs were calculated using the life cycle cost analysis (LCCA) method, based on the designed system specifications. The amount of heating required for each residence was calculated using the DD method. The base temperature was taken as 18.7° C. From the economic analysis results, the researchers found that the natural gas heating system showed unquestionable economic superiority.

Durmayaz and Kadioglu (2003) [22] estimated the seasonal energy demand and fuel consumption in a building for the major cities of Turkey – such as Istanbul, Ankara, Adana, Bursa and Konya – using the degree-hour (DH) method. The seasonal natural gas consumption in each city center under consideration for the worst conditions is approximately three times as much as those of the best conditions. The total seasonal natural gas consumptions in these five city centers for the worst (single-glazed) and the best (double-glazed) conditions are approximately 8.9 and 3.3 Gm^3, respectively. Since 50.8% of the total population in Turkey is thought to live in these large city centres, it was stated that the total amount of these estimates can be interpreted as a good indicator of the energy demand and fuel consumption of buildings in all major cities in Turkey.

Kaynakli (2008) [23] subsequently performed a more detailed investigation, determining the dependence of the heating energy requirement and associated fuel consumption for single and double-glazed windows and various types of construction materials, considering building design properties including glazing surface area (GAP) and air exchange rate (*I*).

Aktemur, C. (2017) [24] conducted a case study for Kocaeli/Turkey to calculate the annual heating energy requirement and natural gas consumption at a base temperature of 15^{o}C. The necessary calculations were carried out using some parameters such as different type of glass, glazing area percentage (GAP), air exchange rate (I), and the number of people (n) living in a prototype building to determine the natural gas consumption. Natural gas consumed for heating in an apartment building was estimated by the best and worst condition. In the worst condition (single-glazed) natural gas consumption was estimated to be fourfold higher than the best condition (triple-glazed).

Arıcı and Karabay (2010) [25] investigated heating costs and energy savings of various fuels such as LPG, fuel-oil, natural gas and coal in case of utilizing double-glazed windows in Turkey. When it is evaluated with regard to heating costs, it is deduced that natural gas was the best fuel for all the climate regions of Turkey.

Torekov et al. (2007) [26] investigated the factors that are effective in selecting heating systems for new buildings in Denmark. They observed that the use of natural gas for heating in Denmark is more economical and central heating should be used where there is a need for more heating, especially in apartment buildings.

Ossebaard et al. (1997) [27] performed a study to compare the heating systems (central and electricity) used in houses in the Netharlands in terms of cost, energy efficiency and air pollution. They figured out that electric heating system is more effective than natural gas heating system when energy efficiency is considered.

Balbay (2015) [28] presented a case study on natural gas consumption on the ground, first and second floors of an insulated 5-storey building heated via a central heating system in Siirt province, Turkey. Domestic temperature change, room thermostat set temperature, boiler set temperature, internal or external aspect of the house, natural gas consumption and cost are were the main factors investigated. In addition, various atmospheric events such as air temperature, wind speed and relative humidity, which indirectly affect natural gas consumption and comfort temperature was examined. The amount of natural gas consumed on the ground floor was approximately 15% more than that of consumed on the first and second floors.

In a comparison made by Kaya (2009) [29], the design of an additional heat pump design with assist of the waste heat of the condensation unit of the natural gas combined-cycle power plant of 2310 MW installed in Sakarya province of Turkey was considered. This system, which was additionally considered for the heating of the houses, evaluated the long-term cost relationship of the combi heating system. The unit cost analysis was conducted to determine whether the heating of the house was economical by means of a heat pump. While the heat pump condenser temperature is advantageous economically at 60°C, it loses its advantage since increasing temperature. If the heat pump condenser temperature is above this temperature, the use of natural gas fuel becomes more economical.

Bowitz and Trong (2001) [30] examined the economic and environmental costs of central heating in some European countries. In their study, a new model for central heating was proposed and a cost-benefit analysis was conducted. In consequence of the study, the social and economic costs of central heating in new buildings were found to be lower than other systems.

Özkan and Onan (2010) [31] investigated effects of different insulation thicknesses and fuel on fuel consumption and thereby on emissions of pollutants such as CO_2 and SO_2 were evaluated. For example, in the building where XPS (extruded polystyrene foam) insulation material and natural gas are used and where the ratio of glazing area to exterior wall area was 0.2 (glazing area percentage), energy saving for the four regions was found to be 13.996, 31.680, 46.613, and 63.071 $/m^2, respectively.

Bos and Weegink (1996) [32] investigated the amount of natural gas consumed in houses in the Netherlands. As a result of the study, they found that the total amount of natural gas consumed in 1994 increased slightly compared to the last years.

De Almeida et al. (2004) [33] investigated the energy consumption of natural gas and electricity usage for heating and other purposes in residential buildings in Portugal, as well as evaluating the different effects on economics and living environment. From the perspective of energy consumption, it was determined that the use of electricity to meet both the heating and the hot water requirements leads to the lowest energy consumption and lowest environmental pollution in the kitchen utilities. From an economic point of view, they deduced that the use of electricity is 45% more economical rather than that of natural gas to meet both heating and hot water needs.

Zwetsloot (1995) [34] examined natural gas used for heating purposes in buildings in the Netherlands. He determined that the amount of energy consumed in buildings heated by central heating is less than the average amount of energy used for heating houses in the Netherlands.

Oguz and Kirmaci (2015) [35] conducted a research for four different building models to investigate economic and environmental impacts of the heating systems used in Bartın/Turkey. Four different heating systems were examined, namely, coal-fired, fuel-oil, and natural gas-based central and individual heating systems. In their study, the cost analysis was carried out to determine which system is more economical by taking into account the conversion of the natural gas-based central and individual heating systems of the building, which was utilized previously a coal-fired central heating system. It was deduced that the most environmentally friendly and economical heating system would be the natural gas central heating system.

Similar to the previous study, Comakli et al. (2008) [36] made cost analysis of central heating systems for different building types and fuels. Within the scope of their study, six different types of buildings in Erzurum, one of the coldest provinces of Turkey, were identified and three different central heating systems used natural gas, coal and fuel-oil were designed by performing the necessary studies for each and the installation and annual operating costs for each system were calculated. Then, the annual operating and installation costs per apartment were compared for each building and fuel type. As a result, it is understood that natural gas, which is one of the most used fuels in central heating systems today, is the most economical fuel for all building types in terms of operating costs and the cleanest fuel. This is followed by systems that use coal in the second place and fuel-oil in the third place.

Yazici et al. (2012) [37] conducted a study to calculate the amount of natural gas, coal, motorin and fuel-oil to meet the annual heat requirement by taking the outdoor temperature of the building at -6 ^{o}C in Denizli province of Turkey and annual fuel cost was calculated by using fuel amounts determined according to type of fuel. At the end of the study it was found that the most suitable fuel to be used to meet the building's annual heat requirement was to be natural gas. The change in the annual fuel costs of coal, motorin and fuel-oil compared to natural gas was calculated to be 10.5%, 447% and 273.8%, respectively.

Ozyaman (2011) [38] made a research that the heating and hot water preperation using a solar-assisted heat pump was aimed to compare with natural gas-based heating system at a workplace with a net usage area of 120 m^2 in Izmir, and the system was operated between November 2009 and April 2010 for 7 days and 24 hours. Heating of net usage area of 120 m^2 in the desired comfort conditions is costed with a total of 530 ₺. The saved amount is 70% of the total heating needs. This means 540 m^3 saving of natural gas usage and 1,510 kg CO_2 emission reduction.

The next chapter introduces methods for calculating heat losses for a house, as well as a method for estimating yearly heating energy requirement and fuel consumption of heating systems utilized.

Chapter 3

ESTIMATING THE HEATING LOAD AND THE SEASONAL HEATING REQUIREMENT OF BUILDINGS

3.1 Introduction

Differences in internal and external building temperatures are critical parameters affecting heat transfer. The heating energy requirements of buildings fluctuate in parallel with the instantaneous changes in indoor and outdoor conditions. Since the energy requirements change depending on the ambient conditions, it is necessary to use a practical and applicable calculation method when designing a building. The heating energy requirement for a building is the minimum energy required for the heating system to maintain the internal environment at a specified comfort level during the year [39].

3.2 Fundamental Assumptions for Case Study

Three basic assumptions that support the calculations :

- Meteorological records have demonstrated that the most severe climatic conditions are not repeated every year because Turkey has a non-uniform climate. Therefore, using outdoor heating design conditions identified by ASHRAE, outdoor air temperature was taken as -4 °C for the city of Kocaeli.
- Because thermal comfort conditions are the determinants of internal climate, they must be provided in terms of maintaining a good indoor environment

without excessive energy consumption. According to TS 825 (thermal insulation requirements for buildings), indoor air temperature was taken as 20°C for all rooms in a house, which is defined as a building containing three bedrooms, two bathrooms, one kitchen and one living room.

- Inner surface resistance and outer surface resistance of the house for external wall surfaces, windows and floor were taken as 0.123 and 0.055 (m^2°C /W), respectively.

3.3 Overall Building Heat Loss

The total heat loss (Q) of a building is determined by the sum of transmission (fabric) heat loss (Q_t) by conduction and convection, heat loss by infiltration (Q_i) and heat loss (Q_v) by ventilation. The general formula used for calculating total heat loss is indicated through the equation (3.1) [42] and Figure 2, respectively.

$$Q = Q_t + Q_v + Q_i \tag{3.1}$$

Energy losses from a typical house occur at a rate of 25% through the roof / attic, 35% through the external walls, 15% through the floor, and 25% through the doors and windows. Figure 2 below displays heat loss in a typical house.

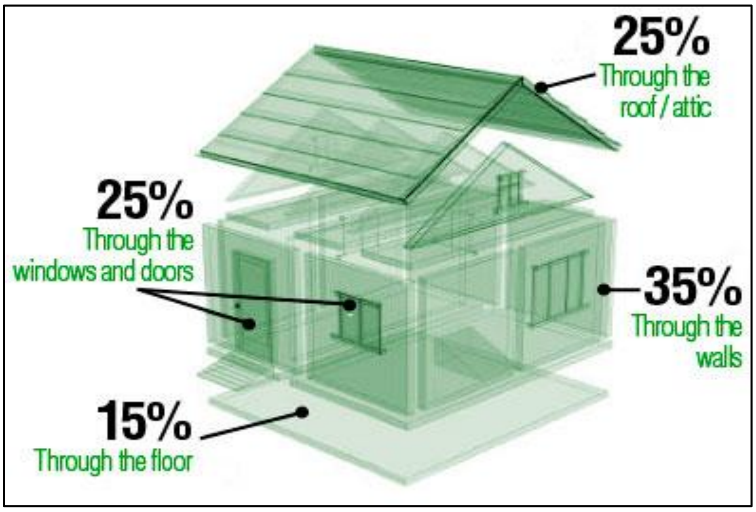

Figure 2: Illustration of Typical Heat Loss from a House [43]

3.3.1 Transmission Heat Loss

Heat will flow through the structure toward lower temperatures in such a way that conduction and convection co-exist when a temperature difference exists between the internal and external sides of a structure. Total fabric heat loss is the sum of the heat losses through the building enclosure (i.e., the walls, roofs, ceilings, windows, doors, and floors) and it can be expressed with equation (3.2) [42] below.

$$Q_t = A \times U \times (T_i - T_o) \tag{3.2}$$

where, Q_t is transmission heat loss [W], A is surface area [m^2], U is overall heat transfer coefficient [W/(m²ºC)], T_i is internal air temperature [ºC], and T_o is external air temperature [ºC].

3.3.2 Ventilation Heat Loss

Natural or mechanical ventilation is used to create a comfortable and healthy environment in buildings. The number of air changes must be determined to calculate heat loss through ventilation. The number of air changes in the building differ between natural and mechanical ventilation because of differences in components, tightness and construction. To calculate the heat loss through ventilation, two different calculation methods are employed, depending on whether the ventilation is natural or mechanical. Ventilation heat loss is estimated for doors and windows in the rooms by aid of the equation (3.3) [42].

$$Q_v = c_p \times \rho \times N \times V \times (T_i - T_o) \tag{3.3}$$

where, Q_v is heat loss by ventilation [W], c_p is specific heat capacity of air [kJ/kg°C], ρ is density of air [kg/m^3], N is air exchange rate [h^{-1}], and V is volume of the room [m^3].

According to the information obtained by TS 825 [41], ρ = 1.184 kg/m^3 , c_p = 1.006 kJ/kg°C and N varies between 1 and 2 per hour in residential buildings. While the most commonly used area is kitchen and N is assumed to be 2.0, the least used area is bedroom 1-2 and N is supposed to be 1.0. N values of other areas in the house are presumed to be 1.0., including living room, bedroom 3, bathroom 1-2.

3.3.3 Infiltration Heat Loss

Air leaking into a house from the outside causes the same amount of hot air to leak out. In this case, the cold outside air leaking into the room needs to be heated up to room temperature. Heat loss by infiltration (air leakage) is the amount of heat required to heat the leaking cold air. Heat loss through infiltration is calculated using formula (3.4) [42].

$$Q_i = c_p \times \rho \times I \times V \times (T_i - T_o) \quad (3.4)$$

where, Q_i is heat loss by infiltration [W], c_p is specific heat capacity of air [kJ/kg°C], and I is air exchange rate [h^{-1}].

Table 2 indicates the average air exchange rates per hour for leaky and modetarely tight building. In accordance with the following information, air exchange rate (I) were taken as 0.5 for the house on the ground floor of the 5-storey building examined.

Table 2: Air Exchange Rates in Buildings [43]

Building	Leaky building	Moderately tight building
Dwellings – 1 storey	1.15	0.40
Dwellings – 2 storeys	1.00	0.35
Apartments – 1 to 5 storeys	1.00	0.50
Apartments – 6 to 10 storeys	1.60	0.55

3.4 Overall Heat Transfer Coefficient

The U-value or U-factor indicates the level of insulation of a material, and it varies with each material. The resulting value demonstrates how much heat is transferred to the material being used. It is the most important property expected from insulation products, and the fact that it is low is one of the reasons of preference of the material. Although it is an important criterion in comparing different materials, it may not always be possible to obtain the correct results, considering the construction materials of the building to be implemented. As shown in Figure 3, the thermal resistance (R) value must also be calculated in order to evaluate the performance of the application. Since the thermal insulation performance is also related to the thermal resistance (R) value, it is calculated by the ratio of the thickness (L) and the thermal conductivity value (k) of each material. The R-value can be obtained using equations (3.5) and (3.6). The U-value has an inverse relationship to the R-value, as can be seen in equation (3.7) [44].

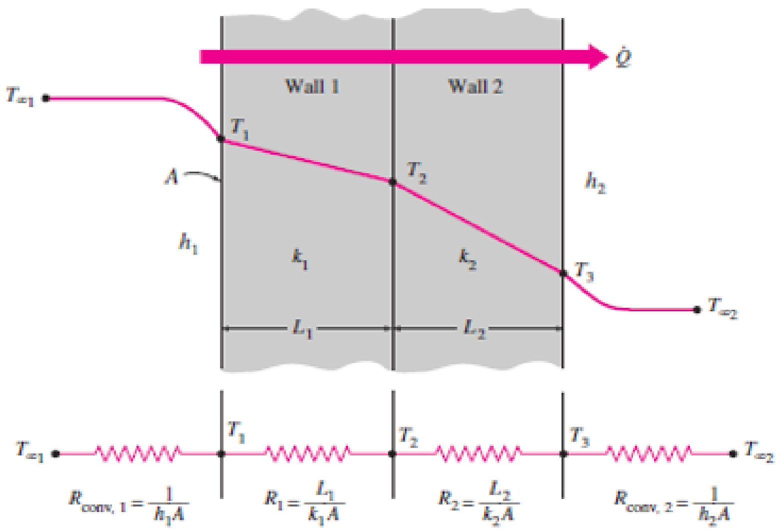

Figure 3: The Thermal Resistance Network [44]

$$R_{total} = R_{conv,1} + R_{wall,1} + R_{wall,2} + R_{conv,2} \quad (3.5)$$

where, R_{total} is the total resistance to heat transfer of the combination, expressed as

$$R_{total} = \frac{1}{h_1 A} + \frac{L_1}{k_1 A} + \frac{L_2}{k_2 A} + \frac{1}{h_2 A} \qquad (\mathrm{m^2 {}^\circ C /W}) \qquad (3.6)$$

$$U = \frac{1}{AR_{total}} = \frac{1}{\frac{1}{h_1} + \frac{L_1}{k_1} + \frac{L_2}{k_2} + \frac{1}{h_2}} \qquad (\mathrm{W/m^2 {}^\circ C}) \qquad (3.7)$$

or the following formula is obtained by replacing R_i with $1/_{h_1}$ and R_o with $1/_{h_2}$

$$U = \frac{1}{AR_{total}} = \frac{1}{R_i + \frac{L_1}{k_1} + \frac{L_2}{k_2} + R_o} \qquad (\mathrm{W/m^2 {}^\circ C}) \qquad (3.8)$$

where R_i and R_o are inside and outside surface resistances [m²°C/W]

3.5 Overall U-values for the Enclosure Sections

3.5.1 The Structure of the External Walls

Heat is broadly lost from the buildings via the exterior walls, windows, floors and ceilings, as well as by ingress of air from the exterior. The majority of heat is lost through exterior walls constructed of conventional building materials, such as perforated brick, concrete and wood [44]. The thermal insulation of the outer walls is applied in three ways: internally, externally or sandwiched between two walls. The structures of the various walls are displayed in Figure 4 below.

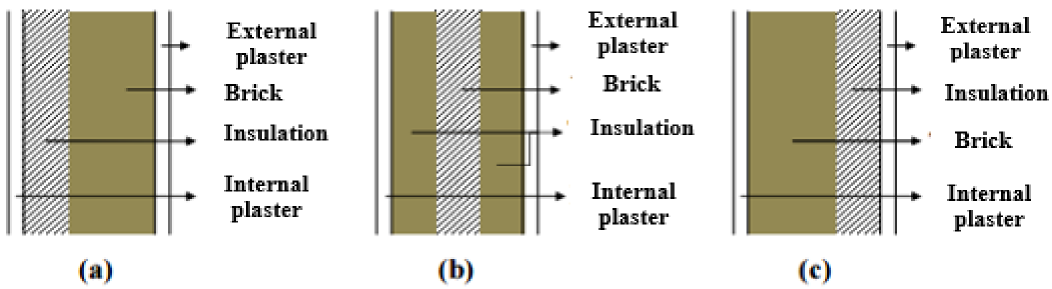

Figure 4: Types of Insulation Applied to Walls: (a) Internal Wall (b) Sandwich Wall (c) External Wall

Insulation applications are usually carried out by a wall model with a composite structure called “sandwich walls.” Insulated sandwich walls are used to calculate the heat loss of the building examined. The structure of the sandwich wall is comprised of 2 cm internal plaster, 7.5 cm horizontal hollow brick, 5 cm glass wool as an insulation material, 7.5 cm horizontal hollow brick, and 2 cm external plaster. Schematic representation of the sandwich wall is depicted in Figure 5. The thicknesses and thermal conductivities of each layer-forming the walls are shown in Table 3.

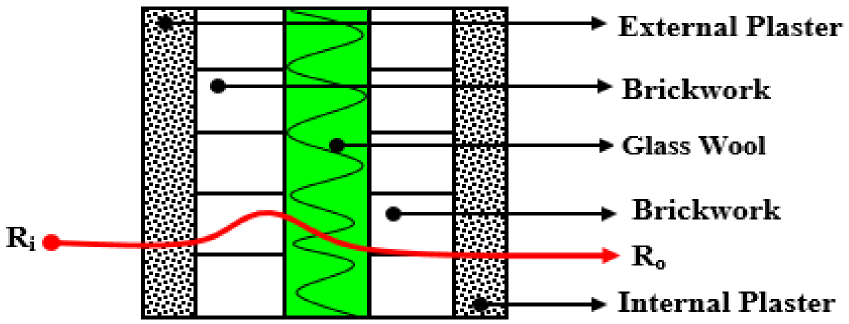

Figure 5: Illustration of the Insulated Sandwich Wall Structure

Table 3: Thermal and Physical Properties of the Wall

Material	**Thickness** (m)	**Conductivity, *k*** [45] (W/m^2 ^{o}C)	**R - value** (m^2 ^{o}C/W)
Surface Resistance Outside	-	-	0.055
Cement plaster with sand aggregate	0.02	0.72	0.028
Brickwork	0.075	0.84	0.089
Insulation (Glass wool)	0.05	0.034	1.47
Brickwork	0.075	0.84	0.089
Cement plaster with sand aggregate	0.02	0.72	0.028
Surface Resistance Inside	-	-	0.123
		U-value (W/m^2 ^{o}C)	**0.54**

3.5.2 The Structure of Windows

A building window provides more than just comfort and aesthetics. It can also be a source of savings when the right materials are selected and properly applied. Windows exhibit minimal resistance to heat flow between various sections of a building envelope. For this reason, special attention should be paid when deciding on the area of the window and the material to be used. A lower U-value means better heat insulation, lower heating cost and greater winter comfort. When the U-value is taken into account, windows are divided into three categories: frame, glass edge and glass centre. The U-value of any window is generally calculated using the following equation (3.9) [45,46].

$$U_{window} = \frac{U_{center}A_{center} + U_{edge}A_{edge} + U_{frame}A_{frame}}{A_{glazing} + A_{frame}} \tag{3.9}$$

Schematic representations of single, double, and triple-glazed windows used in the calculations of heat loss are displayed in Figure 6.

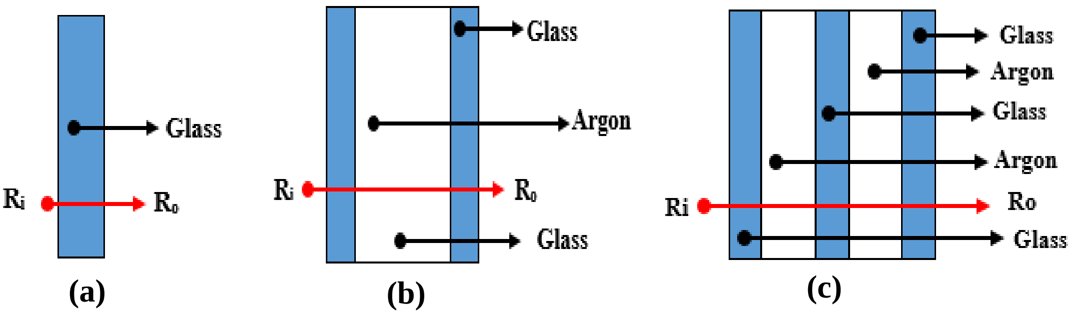

Figure 6: Types of Glazed Windows: (a) Single (b) Double (c) Triple

U-values used in the heat loss calculations are selected by considering the performance tables of the companies [45] :

- Single-glazed window: 5.8 Wm^2/^{o}C.

- Double-glazed window 12 mm with argon filled: 2.7 $Wm^2/^oC$.
- Triple-glazed window 44 mm with argon filled: 0.75 $W/m^2\,^oC$.

3.5.3 The Structure of the Ground Floor

The structure of the ground floor of the building examined consists of 20 cm unreinforced concrete, 10 cm extruded polystyrene foam (XPS) as an insulation material, 5 cm cement mortar, 7.5 cm horizontal hollow brick, and 0.7 cm laminate as flooring material. Schematic representation of the ground floor is shown in Figure 7. The thicknesses and thermal conductivities of each layer-forming floor are presented in Table 4.

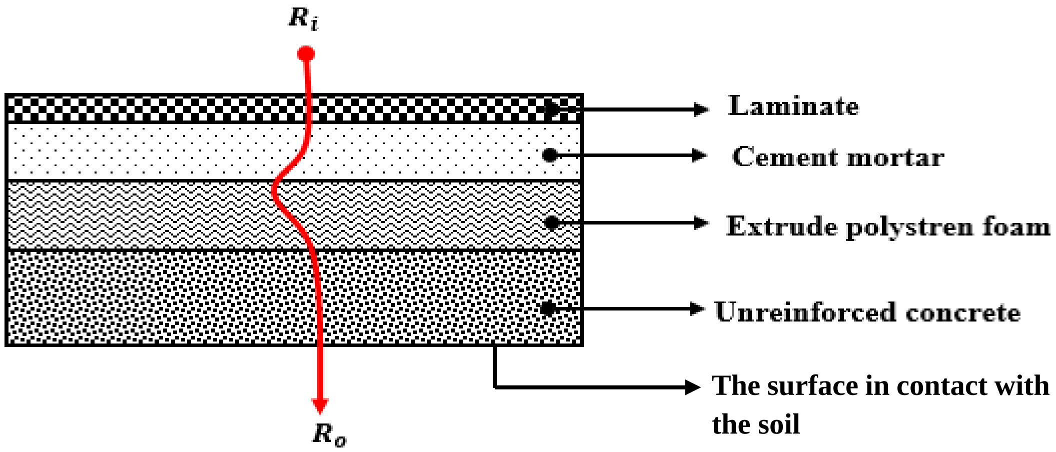

Figure 7: Illustration of the Ground Floor Structure

Table 4: Thermal and Physical Properties of the Ground Floor

Material	**Thickness**	**Conductivity, *k*** [45]	**R - value**
	(m)	($W/m^2\,^oC$)	($m^2\,^oC/W$)
Surface Resistance Outside	-	-	-
Laminate	0.007	0.13	0.054
Cement mortar	0.05	1.73	0.029
Extrude polystren foam	0.1	0.035	2.86
Unreinforced concrete	0.2	1.65	0.12
Surface Resistance Inside	-	-	0.123
		U - value ($W/m^2\,^oC$)	**0.32**

3.6 Degree-Day Concept

A prominent approach for determining annual heating energy requirements is the degree-day (DD); its widespread popularity can be attributed to its accuracy. It is also noteworthy that DD values can be calculated for a certain timeframe, and these are important data in that they indicate the cumulative sum of the variance between the mean outdor air temperature and the base temperature. It should be noted that DDs are identified solely by considering the positive figures for the temperature variance. Although the temperature data are basic DD calculation data, a number of additional factors, such as humidity, wind speed, intensity of radiation, duration of sunshine, and urbanisation, also have a considerable impact; therefore, these meteorological factors need to be considered in DD calculations [46]. Although there are many DD indexes that consider temperature and other meteorological factors, they are not widely used due to their complexity. Extensively used major DD indexes include: Heating Degree-Day (HDD), Cooling Degree-Day (CDD), Growing Degree-Day (GDD), Freezing Degree-Day (FDD), Melting Degree-Day (MDD), and Weighted Degree-Day (WDD) [47]. DDs have a wide range of uses, including [48-50]:

- Determination of the energy used for heating/cooling purpose(s) in residential buildings,
- Determination of the start and end times of the heating/cooling seasons,
- Forecasting combustion efficiency with the aid of fuel consumption calculations,
- Energy production and distribution,
- Determination of future energy requirements,
- Determination of optimum insulation thickness,
- Determination of climatic change,

- Determination of energy policies.

HDD increases as the mean outdoor air temperature decreases, resulting in an increase in the fuel or energy needed for heating. Knowing the annual HDD of any settlement makes it easier to estimate and plan a settlement's heating fuel or energy requirements. Countries employ several techniques to calculate HDD; most countries use the following equation (3.10) [49,50].

$$HDD = \sum_{j=1}^{N} (T_i - \overline{T_o})_j \quad if\ (\overline{T_o} \leq T_b)_j \tag{3.10}$$

where, T_i and T_b are assumed to be constant and expressed as interior design temperature and a base temperature, respectively. $\overline{T_o}$ is the daily average outdoor temperature recorded at a meteorology station. N is the number of days in a heating period when $\overline{T_o} \leq T_b$. Therefore, HDD is determined on the condition that $\overline{T_o} \leq T_b$.

The versatility of HDD computation is one of the central benefits, and there are still many different ways to calculate the HDD values of different countries. However, to facilitate universality of use, the Statistical Office of the European Communities (EUROSTAT) proposes that (3.11) and (3.12) should be used with respect to the total heating season for the computation of the overall HDD [49-52].

$$HDD = \sum_{j=1}^{N} (T_b - T_{o,j})\ if\ (T_o < T_b) \tag{3.11}$$

$$HDD = 0\ if\ (T_o > T_b) \tag{3.12}$$

where, T_b is base temperature, $T_{o,j}$ is daily average outdoor air temperature measured at a meteorology station, and *N* is the number of days. Each HDD value is determined provided that $T_o < T_b$. As seen from equation (3.12), HDDs only receive positive values; otherwise, it will be zero. Using following equation (3.13), the daily mean outdoor air temperature, T_o, is determined by taking the average of the measured maximum and minimum temperatures during a day [53].

$$T_{o,j} = \frac{(T_{o,min} + T_{o,max})}{2} \tag{3.13}$$

where $T_{o,min}$ and $T_{o,max}$ are minimum and maximum temperatures recorded during a day [°C], respectively.

3.7 Determination of Energy Requirement and Fuel Consumption

The energy need for heating in residential buildings is increasing due to the outside temperature fluctuations. HDD values calculated based on outdoor air temperatures can be used to easily calculate heating energy demand, which enables energy companies to create fuel distribution plans based on changes in HDD over the course of a year, which balances supply and demand [49-53]. Figure 8 describes that there is relationship between energy demand and outside air temperature. It is obvious that heating energy requirement is inversely proportional to outside air temperature.

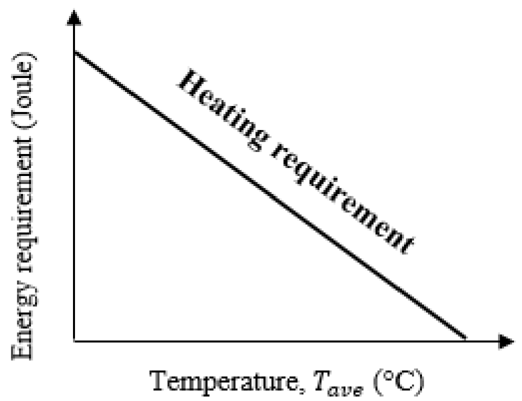

Figure 8: Relationship of Energy Demand and Mean Outside Air Temperature [53]

If HDD and estimated heat loss values are known for a residence or apartment building, heating energy requirement and fuel consumption for that building can be easily calculated for a specific period (day, month, or year). For example, the natural gas needed to heat a building in a specific settlement area can be assessed for a specific period.

Energy companies can use HDD to determine the volume and capacity of heating-ventilation installations and estimate the amount of energy required during the highest energy usage periods because HDD is a practical indicator of energy demand. HDD is also used to identify the annual energy and fuel demand for a specific location. As the HDD in a zone decreases, the amount of fuel required to heat that zone decreases, and as the HDD increases, the amount of fuel required for heating that zone increases. Seasonal heating energy requirement in a building can easily be expressed as [48-55]:

$$D = \frac{Q \cdot HDD \cdot \frac{24h}{1\,day} \cdot \frac{3600s}{1h}}{(T_i - T_o)} \tag{3.14}$$

Equation (3.14) is simplified as follow:

$$D = \frac{86400 \cdot Q \cdot HDD}{(T_i - T_o)} \tag{3.15}$$

where, D is energy demand [J], Q is the total heat loss of a building [W], HDD is the total number of DDs in a year for the heating period [°C.day], and $T_i - T_o$ is design indoor and outdoor air temperature difference [°C].

Yearly heating energy requirements in residential buildings are largely derived from fossil fuels and partly from electricity and other sources of energy. If the total energy demand for any building is known, it is possible to calculate how much fuel is consumed, based on natural gas and air-source heat pump heating systems through the following equations (3.16) and (3.17), respectively [52].

$$FC = \frac{D}{LHV \cdot \eta} \tag{3.16}$$

$$FC = \frac{D}{LHV \cdot COP} \tag{3.17}$$

where, FC is yearly fuel consumption for heating [m^3, kWh], D is energy demand [J], LHV is lower heating value of natural gas and electricity [J/m^3, J/kWh], η and COP are the heating-system efficiencies.

Similar to above equations (3.16) and (3.17), the total fuel consumption in a city for heating purposes can be calculated with the following equations (3.18) and (3.19) [52].

$$(FC)_c = n\frac{D}{LHV \cdot \eta} \tag{3.18}$$

$$(FC)_c = n\frac{D}{LHV \cdot COP} \tag{3.19}$$

where, n is the number of residences in the city and $(FC)_c$ is the yearly fuel consumption of a city.

In next chapter, performance evaluations are carried out by using the HDDs in a typical house in Kocaeli.

Chapter 4

PERFORMANCE EVALUATIONS BY USING THE HDDs IN A TYPICAL HOUSE IN KOCAELİ

4.1 Description of the Typical House

Climate conditions are the main determinant of housing types in Turkey and around the world. Natural conditions such as geological structure and vegetation also determine housing types. However, recent economic and cultural development in Turkey has reduced the impact of the natural environment on housing types. Reinforced concrete houses are becoming increasingly widespread in the Marmara and the Aegean regions as a result of industrialization [54].

A large majority of houses in the city of Kocaeli, located in the Marmara region, consist of concrete buildings. A house located on the ground floor of a five-storey building with three bedrooms, two bathrooms, a kitchen and a living room was selected to determine heat loss. The layout of the ground floor is shown in Figure 9.

The temperature of all rooms is set at 20 °C, and the dimensions (in m) of walls, windows and doors that do not lose heat are not subject to evaluation (white-colored cells). Before calculating energy losses, the dimensions of all facades of the house are shown in Tables 5-6. Table 7 is tabulated for the calculation of the net area of walls according to the facades.

Table 5: Lengths and Heights of Walls by Facades

Room	North (m)		South (m)		East (m)		West (m)	
	L	H	L	H	L	H	L	H
Kitchen	4.61	2.8	4.01	2.8	0	0	4.01	2.8
Living room	0	0	6	2.8	0	0	5.49	2.8
Bedroom 1	0	0	2.75	2.8	0	0	0	0
Bedroom 2	0	0	2.75	2.8	0	0	3.23	2.8
Bedroom 3	0	0	3.51	2.8	5.75	2.8	0	0
Bathroom 1	1.2	2.8	0	0	0	0	0	0
Bathroom 2	1.2	2.8	0	0	0	0	0	0

Table 6: Lengths and Heights of Windows by Facades

Room	North (m)		South (m)		East (m)		West (m)	
	L	H	L	H	L	H	L	H
Kitchen	0	0	0	0	0	0	1.4	1.4
Living room	0	0	2.4	1.4	0	0	2.4	1.4
Bedroom 1	0	0	1.4	1.4	0	0	0	0
Bedroom 2	0	0	1.4	1.4	0	0	0	0
Bedroom 3	0	0	1.4	1.4	0	0	0	0
Bathroom 1	0.4	0.6	0	0	0	0	0	0
Bathroom 2	0	0	0	0	0	0	0	0

Table 7: The Net Area of Walls by Facades

Room	North (m)	South (m)	East (m)	West (m)
Kitchen	12.91	11.23	0	9.27
Living room	0	13.44	0	12.01
Bedroom 1	0	5.74	0	0
Bedroom 2	0	5.74	0	9.05
Bedroom 3	0	7.87	16.11	0
Bathroom 1	3.12	0	0	0
Bathroom 2	3.36	0	0	0

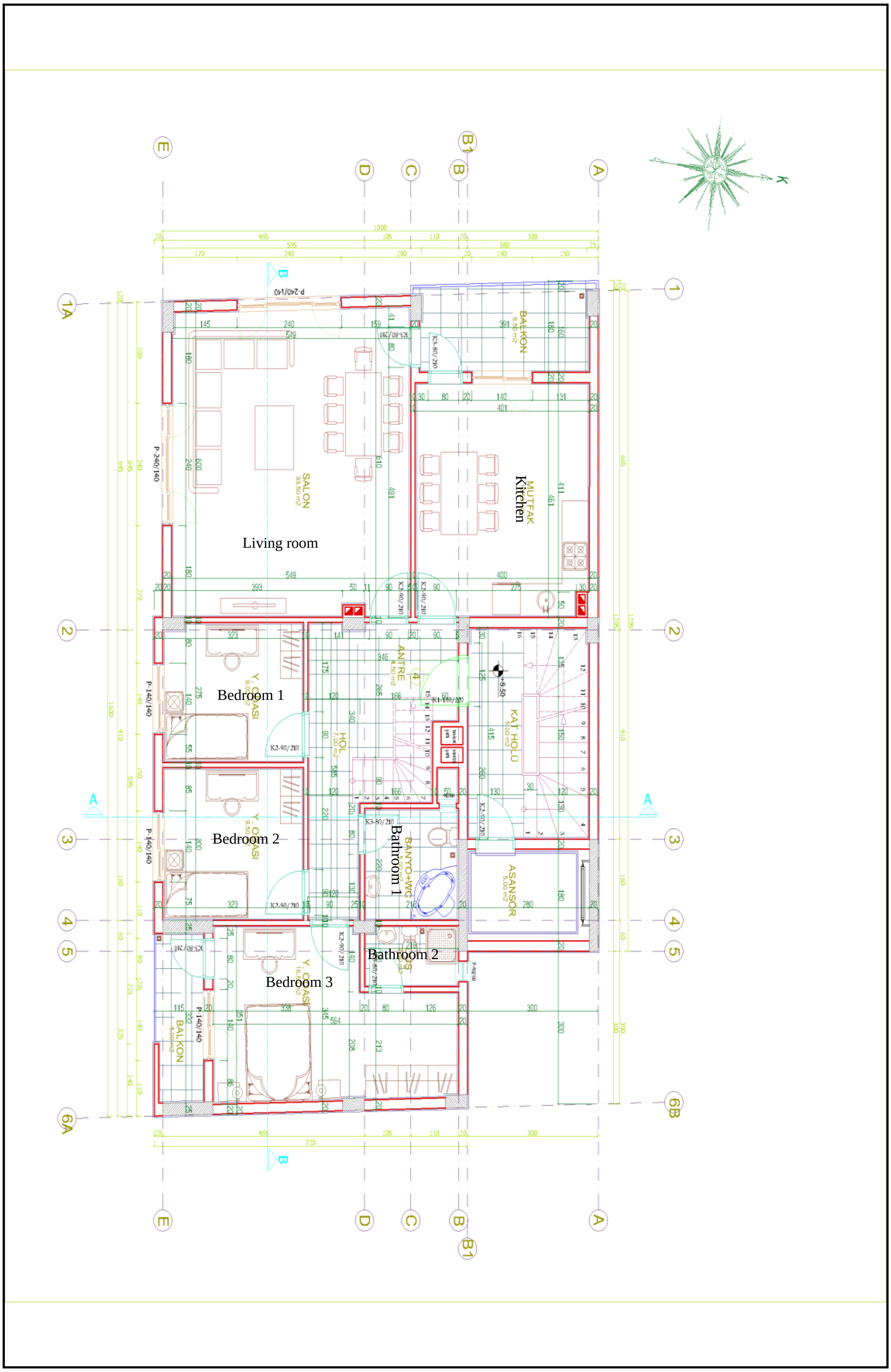

Figure 9: A Typical House in Kocaeli [55]

4.2 Energy Loss Calculations

Using equation (3.2), Table 8-12 express transmission heat losses due to single, double-, and triple-glazed windows, walls, and floor, respectively. Using equation (3.3) and (3.4), Tables 13-14 indicate infiltration and ventilation heat losses through rooms, respectively. Ultimately, using equation (3.1), Tables 15-17 are created to give a general review of the heat losses through all rooms considering single-, double, and triple- glazed windows.

Table 8: Transmission Heat Loss through Single-Glazed Windows

Room	U-value	Area	T_i	T_o	ΔT	Q_t
Kitchen	5.8	1.96	20	-4	24	272.8
Living room	5.8	6.72	20	-4	24	935.4
Bedroom 1	5.8	1.96	20	-4	24	272.8
Bedroom 2	5.8	1.96	20	-4	24	272.8
Bedroom 3	5.8	1.96	20	-4	24	272.8
Bathroom 1	5.8	0.24	20	-4	24	33.4
Bathroom 2	5.8	0	20	-4	24	0
					Total (W)	**2060.2**

Table 9: Transmission Heat Loss through Double-Glazed Windows

Room	U-value	Area	T_i	T_o	ΔT	Q_t
Kitchen	2.7	1.96	20	-4	24	127
Living room	2.7	6.72	20	-4	24	435.5
Bedroom 1	2.7	1.96	20	-4	24	127
Bedroom 2	2.7	1.96	20	-4	24	127
Bedroom 3	2.7	1.96	20	-4	24	127
Bathroom 1	2.7	0.24	20	-4	24	15.6
Bathroom 2	2.7	0	20	-4	24	0
					Total (W)	**959**

Table 10: Transmission Heat Loss through Triple-Glazed Windows

Room	U-value	Area	T_i	T_o	ΔT	Q_t
Kitchen	0.75	1.96	20	-4	24	35.3
Living room	0.75	6.72	20	-4	24	121
Bedroom 1	0.75	1.96	20	-4	24	35.3
Bedroom 2	0.75	1.96	20	-4	24	35.3
Bedroom 3	0.75	1.96	20	-4	24	35.3
Bathroom 1	0.75	0.24	20	-4	24	4.3
Bathroom 2	0.75	0	20	-4	24	0
					Total (W)	**266.4**

Table 11: Transmission Heat loss through Walls

Room	U-value	Area	T_i	T_o	ΔT	Q_t
Kitchen	0.56	33.4	20	-4	24	449
Living room	0.56	25.5	20	-4	24	342.1
Bedroom 1	0.56	5.7	20	-4	24	77.2
Bedroom 2	0.56	14.8	20	-4	24	198.7
Bedroom 3	0.56	24	20	-4	24	322.1
Bathroom 1	0.56	3.1	20	-4	24	41.9
Bathroom 2	0.56	3.4	20	-4	24	45.2
					Total (W)	**1476.1**

Table 12: Transmission Heat Loss through the Ground Floor

Room	U-value	Area	T_i	T_o	ΔT	Q_t
Kitchen	0.32	19.5	20	-4	24	149.8
Living room	0.32	33.5	20	-4	24	257.3
Bedroom 1	0.32	9.5	20	-4	24	73
Bedroom 2	0.32	9	20	-4	24	69.1
Bedroom 3	0.32	16.5	20	-4	24	126.7
Bathroom 1	0.32	2.5	20	-4	24	19.2
Bathroom 2	0.32	5	20	-4	24	38.4
					Total (W)	**733.5**

Table 13: Ventilation Heat Loss through Rooms

Room	c_p	ρ	Volume	N	ΔT	Q_v
Kitchen	1.006	1.184	56.6	2.0	24	896.6
Living room	1.006	1.184	93.8	1.5	24	1114.3
Bedroom 1	1.006	1.184	26.6	1.0	24	210.7
Bedroom 2	1.006	1.184	25.2	1.0	24	199.6
Bedroom 3	1.006	1.184	46.2	1.5	24	548.9
Bathroom 1	1.006	1.184	7	1.5	24	83.2
Bathroom 2	1.006	1.184	14	1.5	24	166.3
					Total (W)	**3219.5**

Table 14: Infiltration Heat Loss through Rooms

Room	c_p	ρ	ACH	Volume	ΔT	Q_i
Kitchen	1.006	1.184	0.5	56.6	24	224.5
Living room	1.006	1.184		93.8	24	372.1
Bedroom 1	1.006	1.184		26.6	24	105.5
Bedroom 2	1.006	1.184		25.2	24	100
Bedroom 3	1.006	1.184		46.2	24	183.3
Bathroom 1	1.006	1.184		7	24	27.8
Bathroom 2	1.006	1.184		14	24	55.5
					Total (W)	**844.2**

Table 15: Overall Heat Loss through Rooms (Single-Glazed Windows)

Room	Ventilation	Transmission	Infiltration	Total
Kitchen	896.5	871.5	224.5	1992.6
Living room	1114.3	1534.8	372.1	3021.2
Bedroom 1	210.7	422.9	105.5	739.1
Bedroom 2	199.6	540.7	100	840.2
Bedroom 3	548.9	721.7	183.3	1453.8
Bathroom 1	83.2	94.5	27.8	205.5
Bathroom 2	166.3	83.6	55.5	305.4
Total (W)	**3219.5**	**4269.7**	**1068.4**	**8557.6**

Table 16: Overall Heat Loss through Rooms (Double-Glazed Windows)

Room	**Ventilation**	**Transmission**	**Infiltration**	**Total**
Kitchen	896.5	725.7	224.5	1777.6
Living room	1114.3	1034.8	372.1	2284.1
Bedroom 1	210.7	277.1	105.5	524.2
Bedroom 2	199.6	394.8	100	625.2
Bedroom 3	548.9	575.9	183.3	1238.8
Bathroom 1	83.2	76.7	27.8	179.1
Bathroom 2	166.3	83.6	55.5	305.4
Total (W)	**3219.5**	**3168.6**	**1068.4**	**7456.4**

Table 17: Overall Heat Loss through Rooms (Triple-Glazed Windows)

Room	**Ventilation**	**Transmission**	**Infiltration**	**Total**
Kitchen	896.5	634	224.5	1755
Living room	1114.3	720.3	372.1	2206.7
Bedroom 1	210.7	185.4	105.5	501.6
Bedroom 2	199.6	303.1	100	602.6
Bedroom 3	548.9	484.1	183.3	1216.2
Bathroom 1	83.2	65.5	27.8	176.4
Bathroom 2	166.3	83.6	55.5	305.4
Total (W)	**3219.5**	**2475.9**	**1068.4**	**6763.9**

4.3 The Case of Kocaeli

Harsh climatic conditions can be characterised using the DD calculation method. Climatic conditions have a considerable impact on heating and cooling energy requirements. Therefore, DD zones are determined using DD values for different geographical regions around the world, especially in heating and thermal insulation applications. The known climate history of a region constitutes a critical part of energy analysis. An accurate estimate of energy consumption for heating is provided using climate data representing long-term averages. This data are usually obtained from past climate data recorded in many meteorological stations for many years [48-53].

Figure 10 were taken from the State Meteorological Affairs General Directorate for Kocaeli, which depicts the change of HDD at a base temperature of 15 °C from 2007 to 2015. It can be clearly seen that HDD reached a peak in 2011 before falling gradually. This means that more eharly heating energy requirement and fuel consumption revealed in 2011 when compared to the other years.

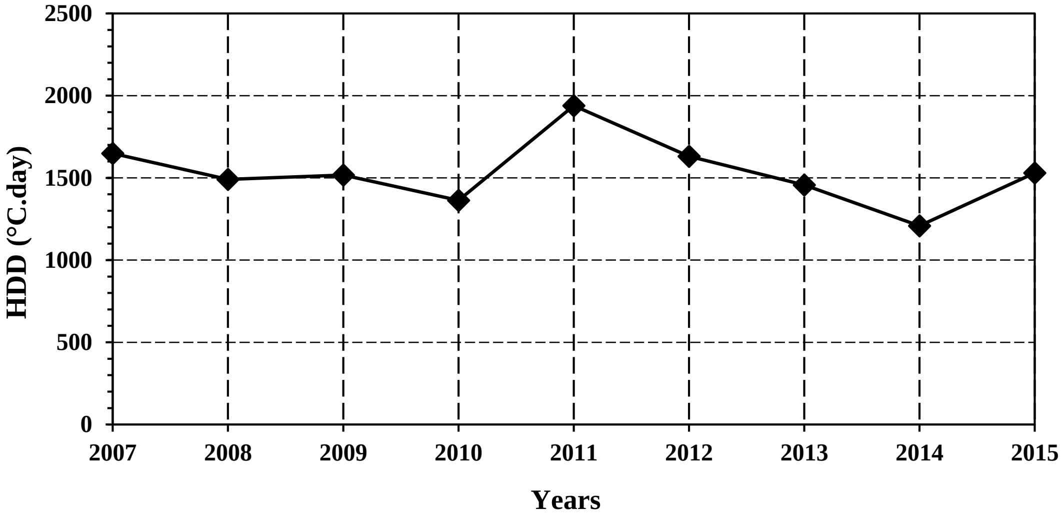

Figure 10: Change of HDD with Years

As indicated by TS 825 (Thermal insulation requirements for buildings), Turkey is divided into four climatic zones relying upon DD values based on the the average temperatures for heating (see Appendix). While region 1 represents the least energy requirement, region 4 represents the most energy requirement. Kocaeli, the reference province positioned in the second climate region, was examined in detail to determine the mean outside air temperatures in 2016. Using equation (3.13), the daily mean outdoor air temperature variation, in light of the records of İzmit meteorology station, is exemplified conjunction with a fitted polynomial function of the 4th order in Figure 11. It is possible to draw conclusion parabolic DD variations occur due to the fact that Kocaeli transitions between Mediterranean and Black Sea climates.

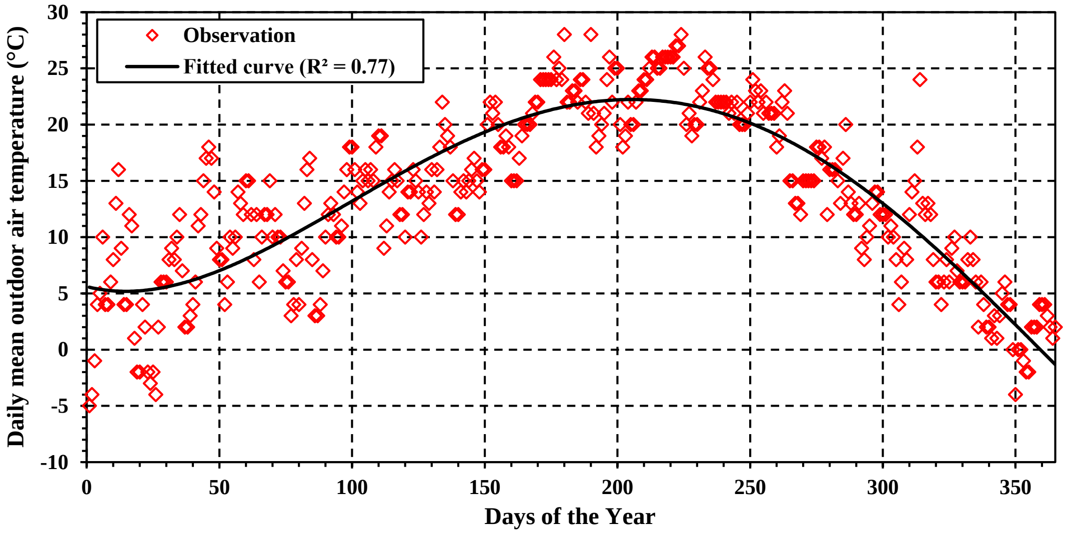

Figure 10: Variation of Daily Outdoor Air Temperature for Kocaeli in 2016

4.3.1 Significance of the Base Temperature

The base temperature in the HDD calculation is the optimal outdoor temperature; it is based on the people's comfort levels and influences the starting date of a building's heating season. There is no internationally accepted rule for selecting base temperature, but are many ways to find it. One of these is conducted by using HDD values. Since people's standards of living (e.g., level of wealth, comfort, etc.) and expectations have consistently risen, several countries have proposed different base temperatures (e.g., 18.3°C in U.S., 18°C in Australia, 15.5°C in the U.K., Germany, New Zealand and Jordan) based on the circumstances within the country [48-54].

Base temperature also known as balance-point or reference temperature is adopted in the energy analysis of residential buildings in the provinces within Turkey to calculate

HDD. For this reason, significant and insignificant differences at base temperatures during a heating season were observed throughout this study. Using equations (3.11) and (3.12), the total number of HDDs for the heating period in 2016 is estimated to be 1407, 1861, 2179 and 2612 (°C-day) at base temperatures of 15, 16, 17, 18.3, 19 and 20 °C, respectively. Table 18 is given to show the HDD values with months of the year.

Table 18: Heating Degree-Days for Various Base Temperatures in 2016

Base temperature	**15 °C**	**16 °C**	**17 °C**	**18.3 °C**	**19 °C**	**20 °C**
Month starting	**HDD (°C-day)**					
January	346	376	415	447,3	469	500
February	157	183	209	245,7	266	295
March	184	213	243	283,3	305	336
April	46	66	91	124,4	144	174
May	23	40	63	94,8	113	140
June	0	3	6	12,1	17	26
July	0	0	0	0	0	0
August	0	0	0	0	0	0
September	7	17	27	40,3	47	57
October	72	94	119	155	176	206
November	182	210	238	274,7	295	324
December	390	420	450	501,3	510	554
Total	**1407**	**1622**	**1861**	**2179**	**2342**	**2612**

Figure 12 indicates the variation in monthly HDD at base temperatures of 15, 16, 17, 18.3, 19 and 20 ºC. A rise in base temperature from 15 to 20 °C results in an increase of 44.6% in terms of HDD in January (the coldest month after December). The only commonality among the six base temperatures is that no heating is required in months of July and August, as the HDD is equal to zero.

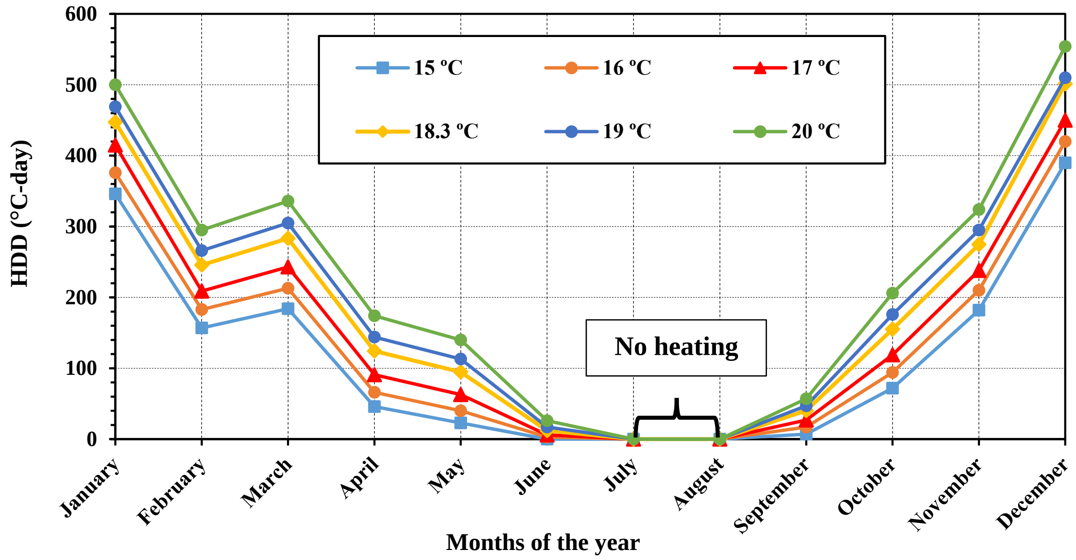

Figure 11: Effect of Different Base Temperatures on HDD

Base temperature should be chosen on the basis of human comfort. The impact on of the start date of a building's heating season on energy demand is notable. For this reason, Figures 13–18 highlight the start and the end of the heating season per base temperature; the changes in the daily HDD numbers considering base temperatures of 15, 16, 17, 18.3, 19 and 20 °C are depicted. For a base temperature of 15 °C, the 266th day (22 September) and 149th day (28 May) of the year represent the start and the end of the heating season. The heating season lasts 248 days per year or 68% of the year, whereas heating is not required between the 150th and 265th days of the year in Kocaeli.

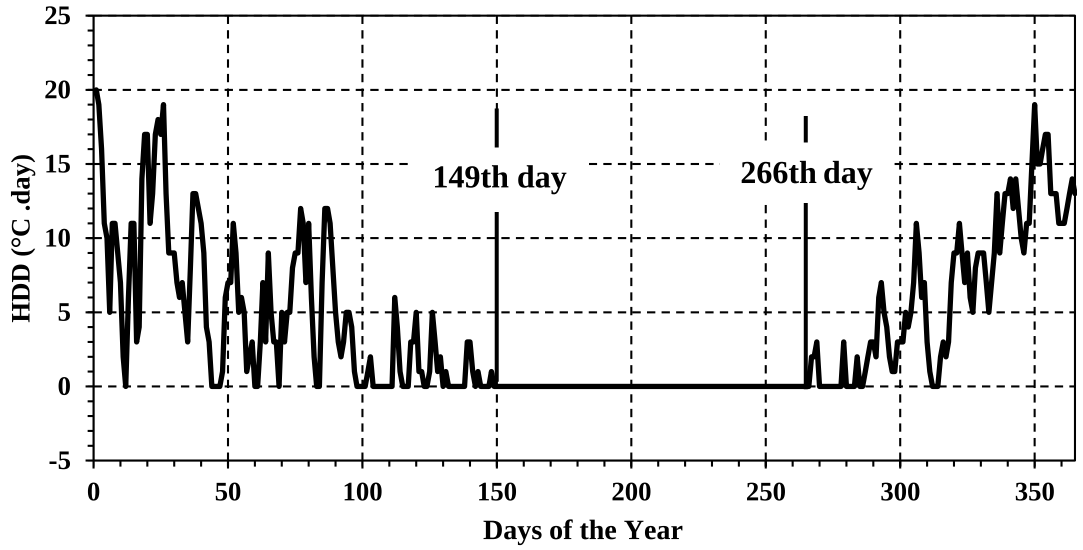

Figure 12: Alteration of Daily HDD at a Base Temperature of 15°C

As seen in Figures 14–15, if the base temperature increases from 15 to 16 °C or to 17 °C, some changes in the heating period will occur. The 264th day (20 September) and 163th day (11 June) of the year appear as the start and the end of the heating season considering base temperatures of 16 and 17 °C, respectively. In this case, the heating season lasts 264 days per year, or 72.3% of the year, while no heating is required between the 164th and 263th days of the year in Kocaeli. The heating period at base temperatures of 16 and 17 °C will be shorter than that of a base temperature of 15 °C. In other words, the latter temperature would result in extra energy demand and fuel consumption.

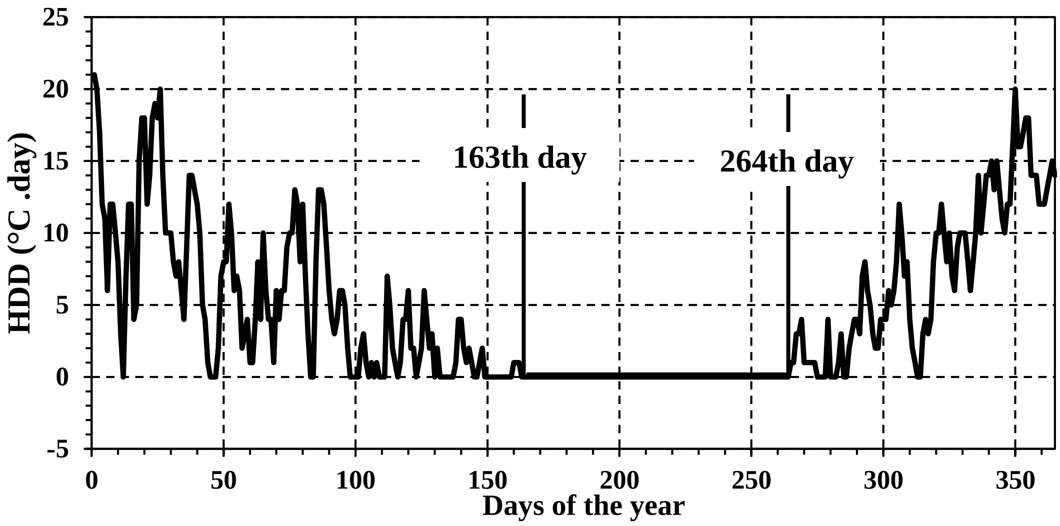

Figure 13: Alteration of Daily HDD at a Base Temperature of 16°C

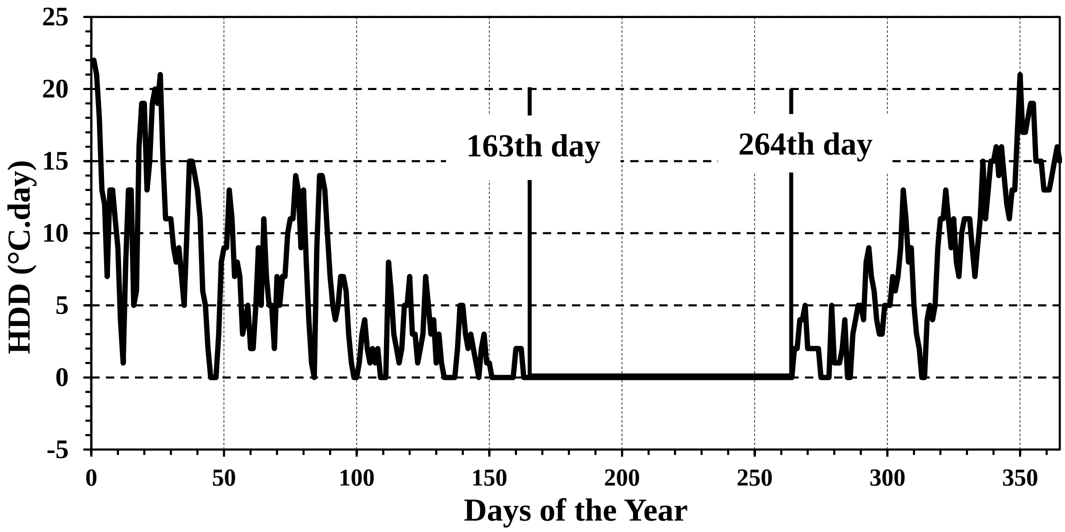

Figure 14: Alteration of Daily HDD at a Base Temperature of 17°C

Figures 16–17 indicate the same characteristics: the start and the end of the heating period, the energy demand and fuel consumption. The 264th day (20 September) and 164th day (12 June) of the year appear as the start and the end of the heating season if 16 and 17 oC, respectively, are adopted as the base temperatures. The heating season lasts 265 days of the year, or 72.5% of the year, while heating is not required between the 165th and 263th days of the year in Kocaeli.

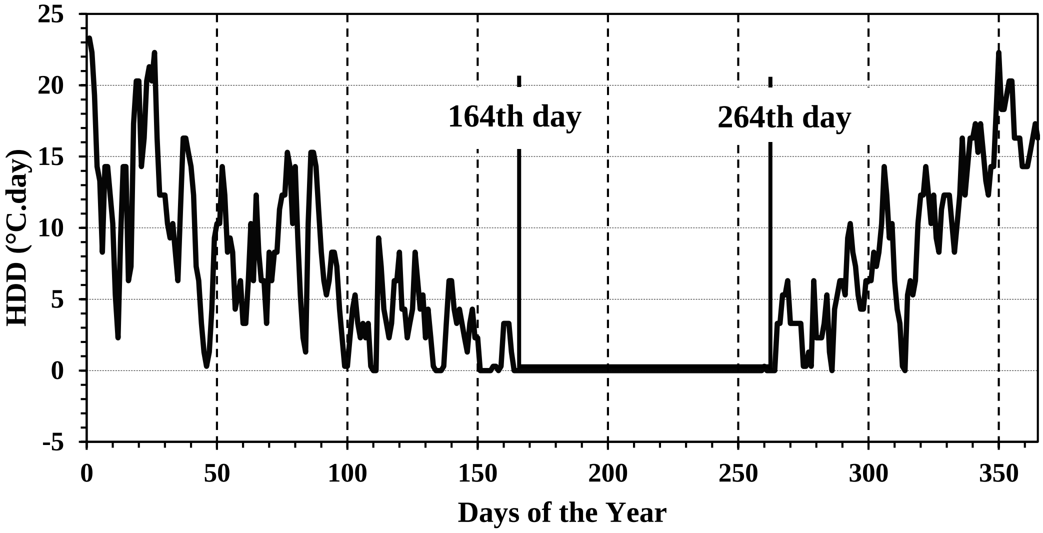

Figure 15: Alteration of Daily HDD at a Base Temperature of 18.3°C

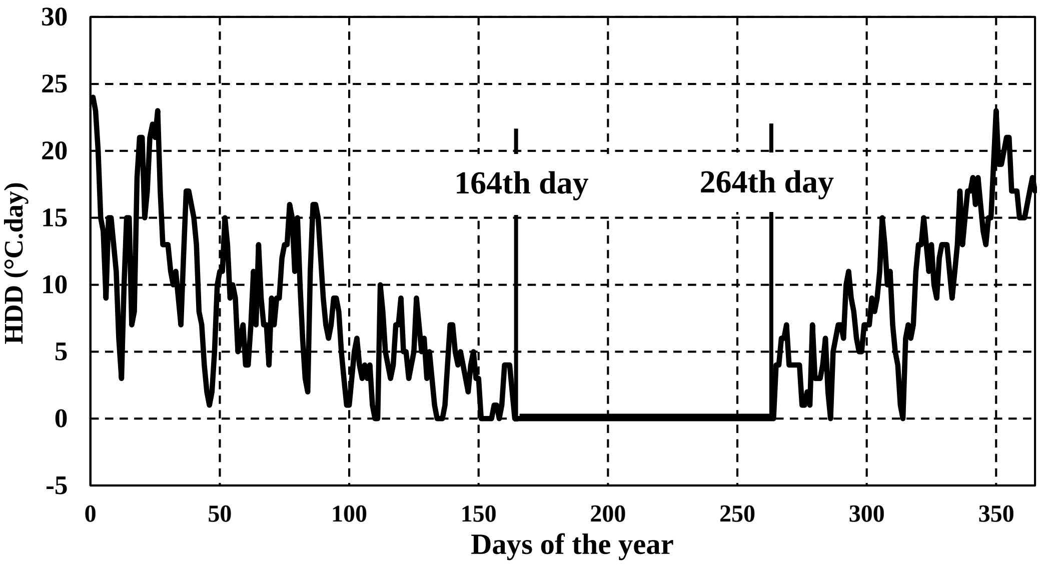

Figure 16: Alteration of Daily HDD at a Base Temperature of 19°C

In Figure 18, similar features are shown at the start of the heating period at base temperatures of 18.3 and 19 °C. The 264th day (18 September) and 165th day (13 June) of the year appear as the start and the end of the heating season. The heating season lasts 266 days in one year, or 73% of the year. Only differences of one or two days are found among the start of the end of the heating season for base temperatures of 16, 17, 18.3 and 19 °C.

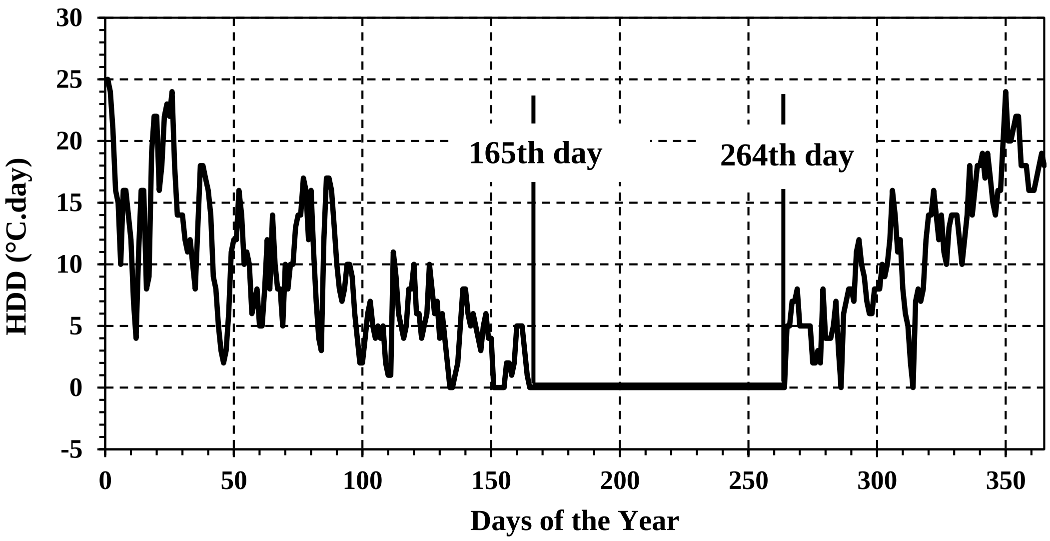

Figure 17: Alteration of Daily HDD at a Base Temperature of 20°C

The characteristics of heating systems employed to determine fuel consumption in the study are given in Table 19 below.

Table 19: Lower Heating Values of Fuels and Performances of Systems

Heating system	**LHV** [56]	**Performance**
Natural gas (boiler)	$34.526\text{x}10^6$ J/m^3	η = 0.88
Electricity (heat pump)	*$3.6\text{x}10^6$ J/kWh	COP = 3.5

*This is estimated by considering the primary energy fuels used for producing electricity. 3.6 MJ of energy (direct heat equivalent) is required to generate 1 kWh of electricity [58].

In Figure 19, the heating energy requirement is determined with equation (3.15) at different base temperatures considering different types of glass and the calculated heat loss. Considering single-glazed windows, the highest energy requirement for heating occurs for a base temperature rise from 17 °C (45 GJ) to 18.3 °C (53 GJ); the least amount is required for a base temperature rise from 18.3 °C (53 GJ) to 19 °C (57 GJ). Meanwhile, when triple glass is used, a minimal heating requirement (about 34 GJ) is evident at a base temperature of 15 °C.

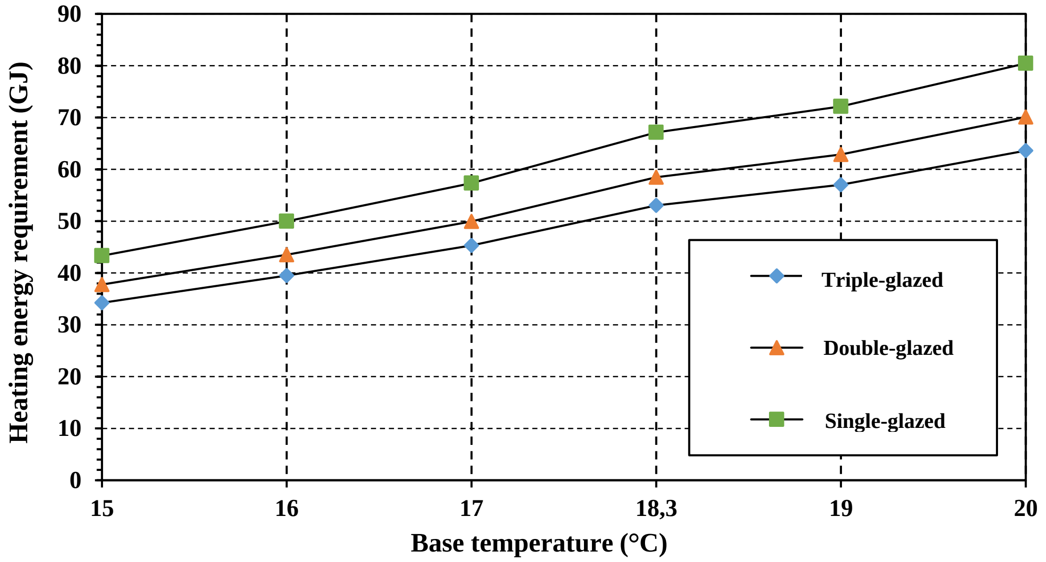

Figure 18: Heating Energy Requirement vs. Base Temperature for Various Glasses

After the heating energy requirement is determined (see Figures 20 and 21 below), the fuel consumption rates for natural gas and electricity are calculated using equations (3.16) and (3.17), respectively. For instance, in Figure 20, at a base temperature of 20°C, natural gas consumption between single and triple-glazed windows is approximately 1339 m^3 whereas the difference in natural gas consumption between single- and double-glazed windows is 1023 m^3.

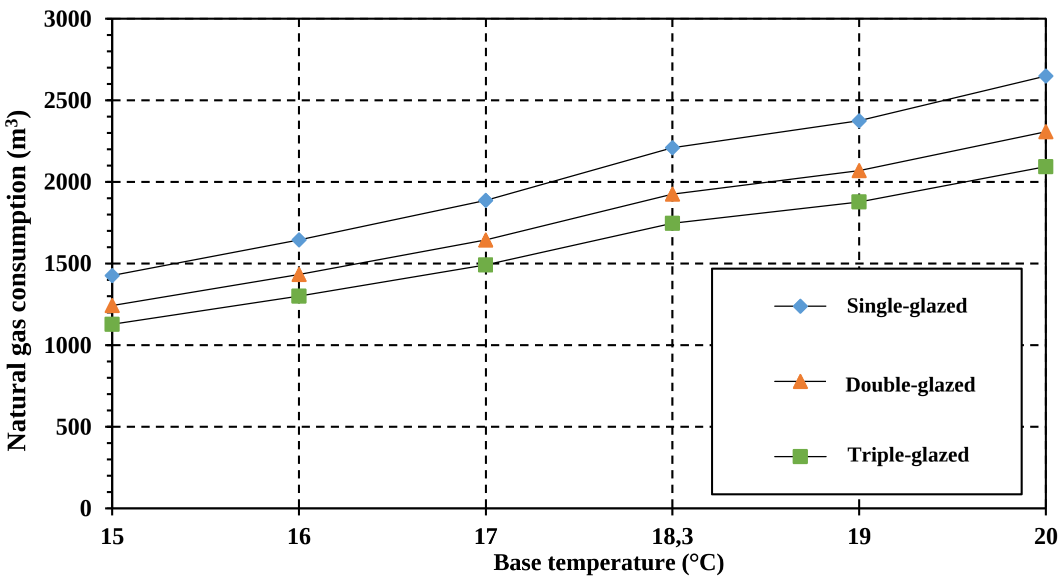

Figure 20: Natural Gas Consumption vs. Base Temperature for Various Glasses

A comparison can be made by converting the unit of the natural gas consumption to the unit of primary energy consumption of the heat pump. So, to be converted to kWh, m^3 is multiplied by 10.64. To illustrate, natural gas consumption is around 15180 kWh (1128 m^3) at a base temperature of 15°C for single-glazed windows (as shown in Figure 20 above) while electricity consumption is about 2719 kWh (as indicated in Figure 21 below). This means that a heat pump consumes about seven times less energy because of its high performance. Moreover, as shown in Figure 20 above, energy loss will approximately double. The reason is that, while electricity consumption is about 3441 and 2719 kWh with the use of single- and triple-glazed windows at the base temperature of 15°C, respectively, electricity consumption is roughly 6388 and 5049 kWh at the base temperature of 20°C.

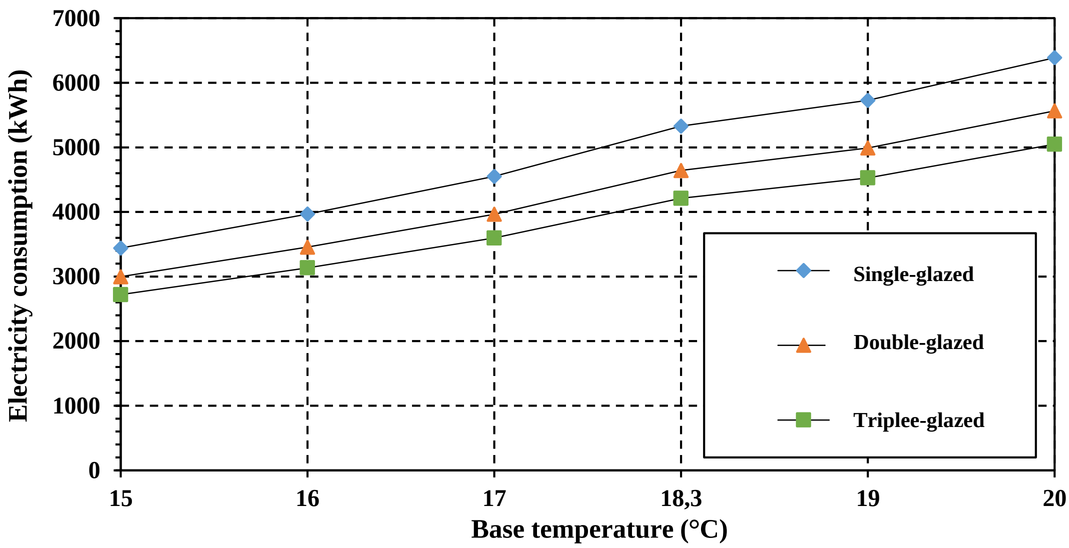

Figure 19: Electricity Consumption vs. Base Temperature for Various Glasses

Figures 22-23 present the heating energy requirements and natural gas consumptions, respectively, at a base temperature of 15 °C between 2007 and 2015. As can be seen the following breakdown, the amount of energy needed for heating reached a peak in

2011 owing to unfavorable weather conditions. The minimum energy amount required for heating took place in 2014 after declining gradually.

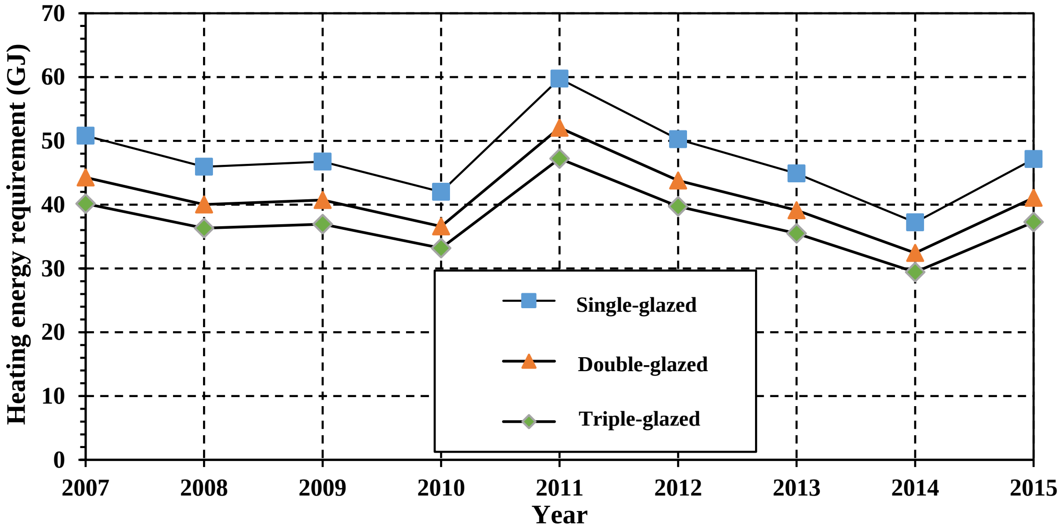

Figure 20: Heating Energy Requirement vs. Past Years at Base Temperature of 15 ^{o}C

It can be seen from Figure 23 that natural gas consumption continuously decreased from 2011 to 2014. While the amount of natural gas consumed was forecasted to be around 1966, 1713 and 1554 m^3 in 2011 (for single-, double- and triple-glazed windows, respectively), the amount of natural gas consumed was about 1225, 1067 and 968 m^3 in 2014. Furthermore, if making a comparison for houses having single- or double-glazed windows in 2014, difference between the amount of natural gas consumed is less than the other years.

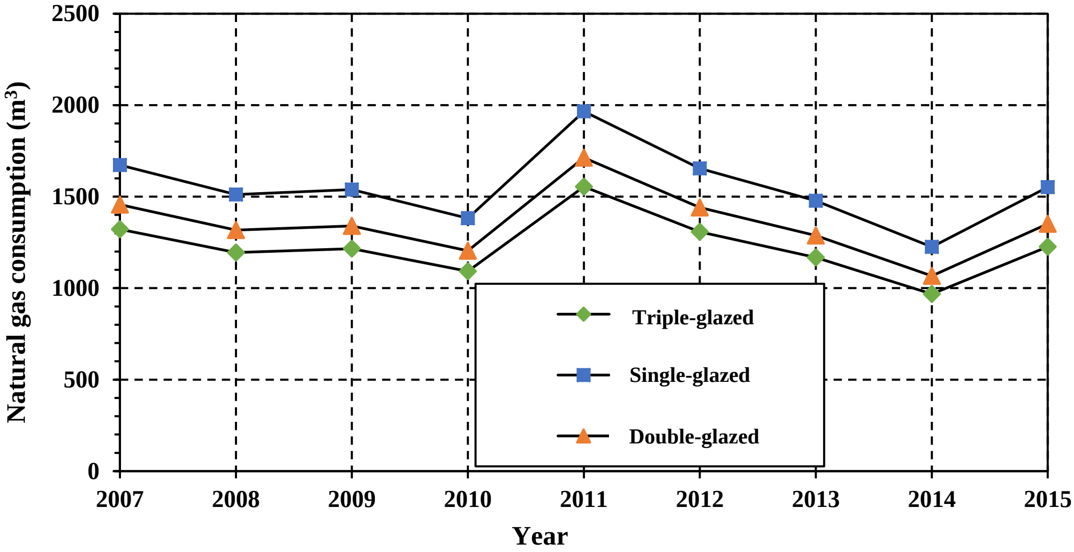

Figure 21: Natural gas consumption vs. Past Years at a Base Temperature of 15°C

Given cities with similar buildings, fuel consumption depends on the total number of residences in Kocaeli. It was predicted that, at the end of 2015, there would be 492,265 houses in the city, according to the information obtained from the Turkish Statistical Institute (TURKSTAT) of the Kocaeli Regional Directorate.

Figures 24 and 25 were created using equations (3.18) and (3.19), assuming that all residences in the city are heated by natural gas and air source heat pump heating systems, respectively. On the one hand, if all houses had single-glazed windows, the gas consumed would be an estimated 1.17 billion m^3. On the other hand, if there were double-glazed windows in all residences, the gas consumed would be 1.02 billion m^3 at a base temperature of 19°C, respectively. The use of double-glazed windows would reduce energy consumption, and the money paid for natural gas would decrease considerably. Energy savings could, moreover, be aproximately 30 and 12% with the use of triple-glazing at a 20°C base temperature compared with single- and double-glazed windows, respectively.

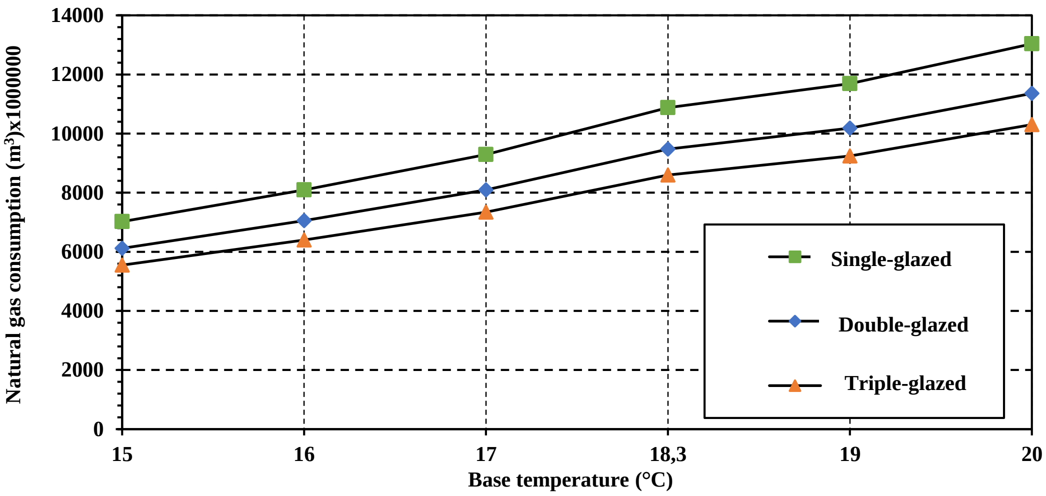

Figure 22: Natural Gas Consumption for the Number of Residences Predicted

Using equation (3.19), considerable difference compared to natural gas will occur when all residences are heated by air-source heat pump as indicated Figure 25. For instance, amount of natural gas consumed is estimated as 9.9 billion kWh (929 million m^3) at a base temperature of 17 °C for single-glazed windows, whilst the amount of electricity consumed is almost 2.2 billion kWh. This means that the energy consumption in residences is reduced by 75%. At a base temperature of 16 °C and in the use of single-, double- or triple- glazed window, electricity consumption is 1.95, 1.70 or 1.55 billion kWh, whereas natural gas consumption is estimated as 8.6, 7.5 or 6.8 billion kWh (861, 750 or 681 m^3).

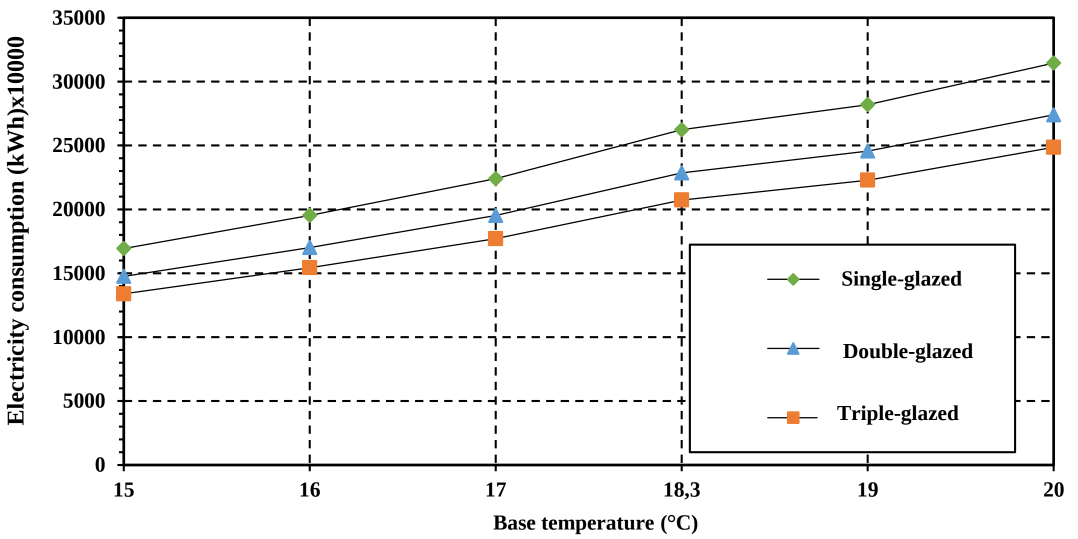

Figure 25: Electricity Consumption for the Number of Residences Predicted

4.4 Determination of CO_2 emission

The combustion of fuels used for heating purposes releases a mixture of 85% carbon dioxide (CO_2), 15% of sulfur dioxide (SO_2), carbon monoxide (CO), particulate matter (PM_{10} and $PM_{2.5}$), and nitrogen oxides (NOx) [59-62]. Typically, only CO_2 emissions are taken into account in the calculations since the emission values other than CO_2 are negligible. To regulate the energy performance of buildings in Turkey, researchers use emission factors (EF) to determine the amount of CO_2 emitted as a result of energy consumption depending on the energy source used. Table 20 shows emission factors of heating systems utilized in this study. Depending on a building's net energy consumption, the amount of annual CO_2 emission by the type of fuel used is calculated via the following equation (4.1) [59].

$$E = FC \times EF \tag{4.1}$$

where, E is CO_2 emission [kg/year], FC is yearly fuel consumption for heting [m^3/year, kWh/year], and EF is emission factor [kg CO_2/kWh].

Table 20: Emission factors of Energy Sources Utilised [59]

Type of heating	EF (kg CO_2/kWh)
Natural gas	0.234
Electricity	0.354

Figures 26-27 indicate CO_2 emissions at different base temperatures by adopting three types of glazed windows, namely single, double and triple. As seen from Figure 26, the minimum CO_2 emission at a base temperature of 15 °C is forecasted to be 1218, 1061, or 963 kg CO_2 for single, double, and triple-glazed window with equation (4.1), respectively. The highest CO_2 emission is observed as 2261 (for single-glazed), 1970 (for double-glazed) and 1787 (for triple-glazed) kg CO_2 at a base temperature of 20 °C due to increased fuel consumption along with the base temperature.

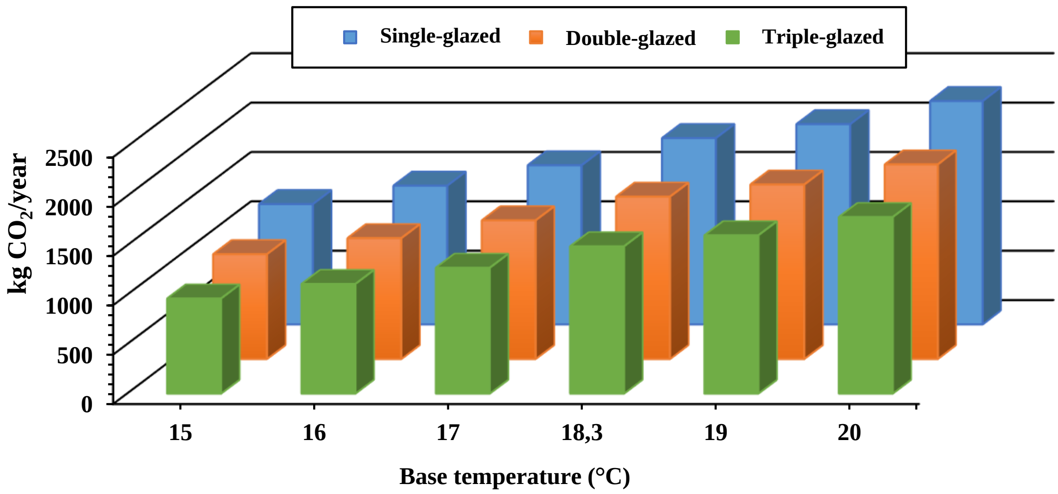

Figure 26: Amount of CO_2 Emission for Electricity by Base Temperatures

Figure 27 shows natural gas used as an energy source has more CO_2 emission due to its lower efficieny. For example, CO_2 from the burning of natural gas is about 4350 kg under the condition of 18.3 °C base temperature and in the use of triple-glazed windows, while CO_2 emission from electricity is nearly 1491 kg. This means that CO_2

emissions emitted from the electricity pollute the environment about 3 times less than natural gas.

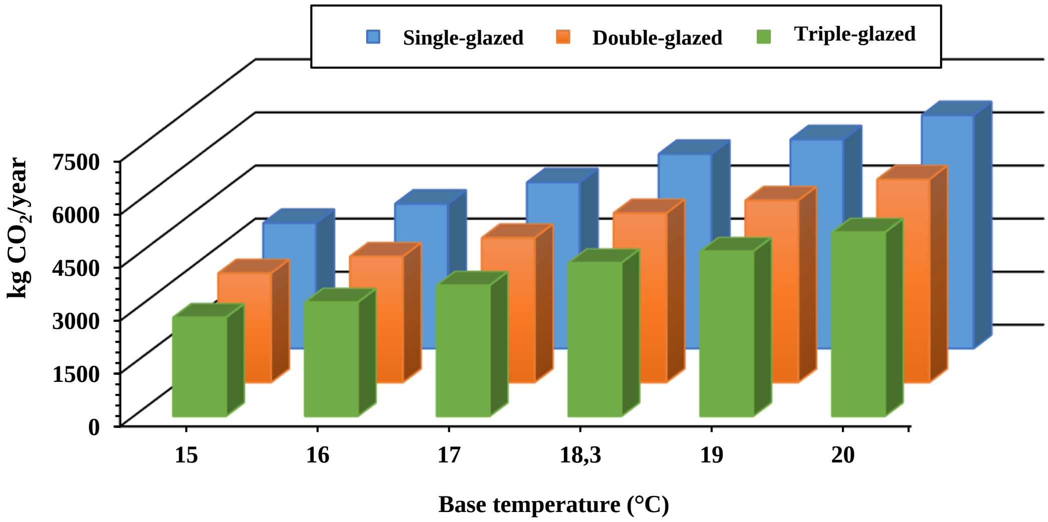

Figure 27: Amount of CO_2 Emission for Natural Gas by Base Temperatures

Figure 28 depicts the breakdown of CO_2 emissions from natural gas at a base temperature of 15 °C between 2007 and 2015. While the lowest CO_2 emission was observed in 2014 as 2410 kg in case of using triple-glazed windows, the lowest CO_2 emission was detected in 2011 as 3869 kg in case of using single-glazed windows. Between 2007 and 2015, due to severe climatic conditions, the highest rate of CO_2 emission revealed in 2011 (4895 kg for single-glazed windows) was employed.

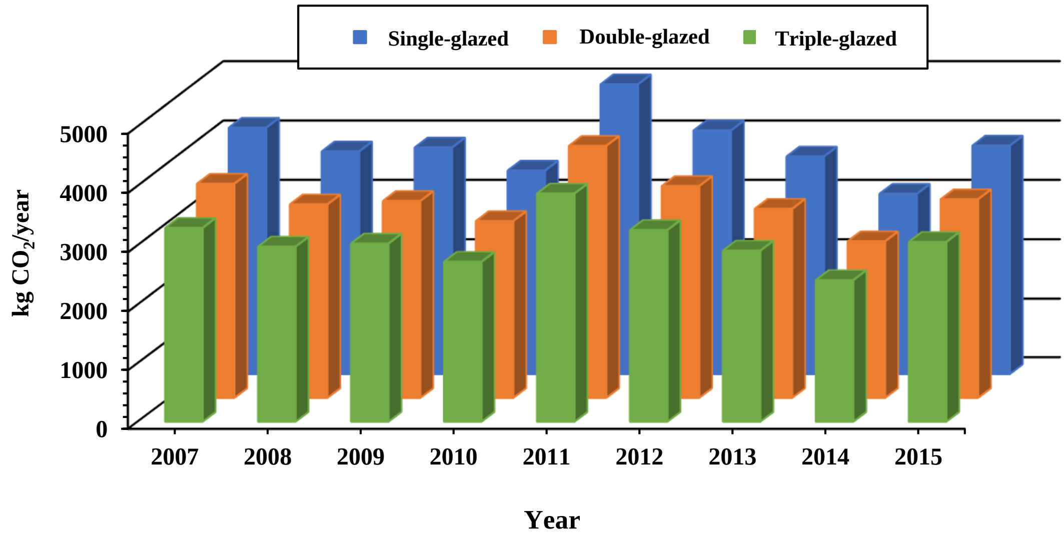

Figure 28: Amount of CO_2 Emission for Natural Gas by Years

In next chapter, by means of economic indicators, a feasibility analysis is carried out to compare natural gas and air-source heat pump heating systems.

Chapter 5

ECONOMIC ANALYSIS

5.1 Economic Feasibility Approach

Life-cycle cost analysis (LCCA) as an engineering economic analysis tool is a method for assessing that includes operation, maintenance, repair and replacement costs as well as initial investment cost. This method can be used as a whole of any design or as part of a whole. There are various formats and economic indicators in the evaluation of the projects. The main ones are; net present value (NPV), savings-to-investment ratio (SIR), simple payback period (SPP) and internal rate of return (IRR) [63]. The following indicators are employed for economic feasibility analysis.

5.1.1 Simple Payback Period

In situations where interest rates vary, it is significant to consider the payback period as it is not possible to forecast the long-term interest rate. It is not a method of measuring the economic viability of an investment, but it is a method that calculates how many years' incomes will meet expenses. It is determined through the following equation (5.1). The simple payback period (SPP) of the investment should be between 1 and 2 years because it is not an acceptable method for longer time periods.

$$\mathrm{SPP} = \frac{\text{Initial investment}}{\text{Annual savings}} \tag{5.1}$$

5.1.2 Net Present Value

Net present value (NPV) (or life-cycle net savings) method is the most appropriate evaluation method for projects with different economic values. This method allows the analyst to evaluate the project at different costs. It equals the difference between the present value of the cash inflows of the investment and the present value of the cash outflows. It is calculated at a certain discount, which represents the cost of capital. It is calculated using following equation (5.2).

$$\text{NPV} = \sum \text{PV Annual Savings} - \sum \text{PV Life Cycle Investments} \quad (5.2)$$

where PV stands for present value.

Based on the NPV calculated, the following cases are taken into consideration [64]:

- If $\text{NPV} > 0$, then investment is feasible.
- If $\text{NPV} < 0$, then investment is not feasible.
- If $\text{NPV} = 0$, then the investor decides to invest according to the advantages and disadvantages of the project.

5.1.3 Internal Rate of Return

Internal Rate of Return (IRR) is a dynamic evaluation method that takes into account the time value of money. IRR is a discount rate that makes the NPV of all cash flows from a particular project equal to zero. It is the discounted rate obtained when SIR = 1, or NPV = 0 [65].

5.1.4 Savings-to-Investment Ratio

Savings-to-investment ratio (SIR) is the ratio of the annual savings of present value to the annual costs of present value of a project. SIR is calculated by the following equation (5.3).

$$\text{SIR} = \frac{\sum \text{PV}_{\text{Annual Savings}}}{\sum \text{PV}_{\text{Life Cycle Investment}}} \quad (5.3)$$

5.2 Feasibility Analysis for Specified Energy Sources

A feasibility study was undertaken to appraise the comparison of natural gas and air-source heat pump heating systems in winter and an air conditioner system as cooling purposes in summer based on initial capital investments, lifetime, discount rate, annual operating costs, etc. Tables 21-22 are presented to determine annual total fuel cost of natural gas, air-source heat pump, and air conditioner systems in case double-glazed windows are employed at a base temperature of 16 ^{o}C.

Table 21: Annual Total Cost of Systems by Double Glass

Old system			
Type of glass	**Double glass**		**Double glass**
Heating and cooling	**Natural gas**		**Air conditioner**
Fuel consumption	m^3/year	kWh/year	kWh/year
	1433	15247	803
Unit cost of fuel	₺/m^3	₺/kWh	₺/kWh
	1.08	0.11	0.42
Annual total cost	1567 ₺/year		337 ₺/year
Total heating and cooling costs = 1906 ₺ / year			

Note: ₺ is the currency in Turkey.

Table 22: Annual Total Cost of Air-Source Heat Pump System by Double Glass

New system (Heat pump)	
Type of glass	**Double**
Fuel consumption	kWh/year
	3456
Unit cost of fuel	₺/kWh
	0.42
Annual total fuel cost	1451.5 ₺/year

Maintenance and repair play a critical role in heating and cooling systems. Therefore, they must be regularly done in order not to decrease the efficiency of them. Accordingly, proper operation of them will save energy.

Tables 23 and 24 are arranged to determine the initial investment cost, maintenance, and replacement cost of systems by accounting for the life of the project. In Table 23, it has been assumed for consumers already living in an existing house that there is no cooling system while installation of natural gas heating system exists and calculations are carried out in this way. There are already domestic installations, combi and radiators for natural gas in house. Therefore, there is no any initial investment cost for natural gas supply.

Product assembly, labor and shipping of an air-source heat pump are costed 13500 ₺. Defrost control board for replacing is 1000 ₺ after 10 years in case of deterioration. Average cost of replacement old thermostat wiring is 200 ₺ per 6 years. Cleaning the fans of the fan motor, checking its bearings, belts, pulleys and connections are costed 250 ₺ per 2 years.

Even though summers are hot under the conditions of Kocaeli, air conditioner is not prevalently employed in the houses. For this reason, an air conditioner is chosen for the living room. Initial investment cost of A++ 18000 Btu/h Inverter air conditioner is 4000 ₺ (including product assembly, shipping, etc.). Unpleasant smells from the air conditioner can negatively affect human health in case necessary measures are not taken. For this reason, detailed air conditioner maintenance should be done per 2 years. Maintenance cost is 150 ₺.

Table 23: Life-Cycle Investment Schedule for an Existing House

Year	Heat pump (₺)	Air conditioner (₺)	Net Amount (₺)	Year	Heat pump (₺)	Air conditioner (₺)	Net Amount (₺)
0	13500	4000	9500	**8**		350	-350
1				**9**	250		250
2		350	-350	**10**	1000	350	650
3	250		250	**11**			0
4		350	-350	**12**	450	350	100
5				**13**			
6	450	350	100	**14**		350	-350
7				**15**			

In Table 24, calculations are made with the assumption that there is no heating and cooling systems for consumers who will live in a newly built house. Natural gas subscription fee is 550 ₺. It is gathered once for every flat and is not returned. Combi, radiators, and installation of interior natural gas lines to be paid are 6000 ₺ (including tax, labor, and assembly). Combi filter and radiator maintenance costs to be paid are 200 ₺ per 2 years in order to avoid a decrease in performance. As a result of regular maintenance, natural gas invoice of consumers for heating will also decrease by 5%.

Table 24: Life-Cycle Investment Schedule for a Newly Built House

Year	Heat pump (₺)	Air conditioner + natural gas (₺)	Net Amount (₺)	Year	Heat pump (₺)	Air conditioner + natural gas (₺)	Net Amount (₺)
0	13500	10550	9500	**8**		350	-350
1				**9**	250		250
2		350	-350	**10**	1000	350	650
3	250		250	**11**			0
4		350	-350	**12**	450	350	100
5				**13**			
6	450	350	100	**14**		350	-350
7				**15**			

Table 25 shows the input values. The annual cost savings are based on the energy cost of the two systems. The discount rate is chosen as 9% from Central Bank of the Republic of Turkey, and both systems are examined over a lifetime of 15 years. The heat pump is sold at the end of its 15-years service life. Residual value is calculated by taking 10% of the initial investment cost of the heat pump.

Table 25: Input Values Based on Old and New system

Annual Savings	454.5 ₺
Discount Rate	9%
Analysis period (years)	15
Residual value	1350 ₺

Tables 26 is created to present the Saving Calculations of the systems. Annual savings are calculated to give the difference among the systems (heat pump and natural gas+air conditioner) examined for 15-years period. PV Annual Savings are determined with equation (5.4) below. It is seen that PV Annual Savings decrease over the years.

PV Annual Savings = Annual Savings /(1+Discount rate)^year (5.4)

Table 26: Saving Calculations

Year	Annual Savings (₺)	PV Annual Savings (₺)	Year	Annual Savings (₺)	PV Annual Savings (₺)
0	0	0	**8**	454.5	228
1	454.5	417	**9**	454.5	209
2	454.5	383	**10**	454.5	192
3	454.5	351	**11**	454.5	176
4	454.5	322	**12**	454.5	162
5	454.5	296	**13**	454.5	148
6	454.5	271	**14**	454.5	136
7	454.5	249	**15**	454.5	125
		∑ PV Annual Savings = 3668 ₺			

Tables 27 and 28 for an existing house and a newly built house, respectively, are displayed PV life-cycle investment (LCI) over a lifetime of 15 years. Net LCI represents difference between old costs and new costs for each year. PV LCI is also calculated with equation (5.5).

PV Life Cycle Investment = Life Cycle Investment / (1+Discount rate)^year (5.5)

Table 27: Investments Made for an Existing House

Year	Net LCI (₺)	PV LCI (₺)	Year	Net LCI (₺)	PV LCI (₺)
0	9500	9500	8	-350	-176
1	0	0	9	250	115
2	-350	-295	10	650	275
3	250	193	11	0	0
4	-350	-248	12	100	36
5	0	0	13	0	0
6	100	60	14	-350	-105
7	0	0	**Residual**	-1350	-371
∑ PV LCI = 8984 ₺					

Table 28: Investments Made for a Newly Built House

Year	Net LCI (₺)	PV LCI (₺)	Year	Net LCI (₺)	PV LCI (₺)
0	2950	2950	8	-350	-176
1	0	0	9	250	115
2	-350	-295	10	650	275
3	250	193	11	0	0
4	-350	-248	12	100	36
5	0	0	13	0	0
6	100	60	14	-350	-105
7	0	0	**Residual**	-1350	-371
∑ PV LCI = 2434 ₺					

Table 29 is given to calculate net cash flows for IRR. It is obtained by subtracting Annual Savings from Net LCI. It can be expressed with the following equation (5.6).

$$IRR = \text{Annual Savings} - \text{Net LCI} \quad (5.6)$$

Table 29: Net Cash Flows for IRR Calculations

Year	An existing house (₺)	A newly built house (₺)
0	-9500	-2950
1	455	455
2	805	805
3	205	205
4	805	805
5	455	455
6	355	355
7	455	455
8	805	805
9	205	205
10	-195	-195
11	455	455
12	355	355
13	455	455
14	805	805
15	1805	1805

By means of calculations made, Table 30 gives the output values of the project and informs us whether the investment made for a heat pump system is economically feasible. In order for a project to be economically feasible, it must be NPV > 0, SIR > 1 and IRR > discounted rate; otherwise, it will not be feasible. As a consequence, a heat pump system is not profitable for an existing house, so it is not economically feasible because it does not fulfill the conditions mentioned above, while the heat pump system for a newly built house is economically feasible as it provides all the conditions.

Table 30: Feasibility Analysis Results for Using Heat Pump instead of Natural Gas

Net Present Value (NPV)	An existing house	A newly built house
	-5317 ₺	1233 ₺
Savings-to-Investment Ratio (SIR)	0.4	1.50
Internal Rate of Return (IRR)	-2%	15%
Simple Payback (years)	20.9	6.5
	Infeasible	**Feasible**

In next chapter, findings obtained during the entire study are carried out, a brief evaluation is made, and recomendations regarding the future of heat pump and natural has heating systems.

Chapter 6

CONCLUSION

One of the simple energy estimation techniques for calculating the required energy demand and therefore fuel consumption is the heating-degree day (HDD) method, which is currently being used by researchers.

In this research, HDD values in 2016 for İzmit, the capital district of Kocaeli province, which is located on the western coast of Turkey, were calculated at the base temperatures of 15, 16, 17, 18.3, 19 and 20 ^{o}C. It is seen that the heating season lasts 248 days in a year, which implies that it covers about 68% of the heating season and it is understood that there is no requirement for the heating between the 150th and 265th days of the year in Kocaeli. Raising the base temperature from 15 to 20 °C causes an increase of about 44.6% in January.

These various base temperatures were moreover analyzed for calculating the yearly heating energy requirement and fuel consumption for natural gas and air-source heat pump heating systems. The annual energy need for heating and fuel consumption was carried out for a typical house on the ground floor where heat losses were calculated with the utilization of single, double, and triple-glazed windows. The amount of natural gas consumed was forecasted to be 15180 kWh at a base temperature of 15 °C in case of using single-glazed windows, whereas the amount of electricity consumed was estimated to be 2719 kWh. This means that the heat pump consumes about 7 times less energy because of its high efficiency.

After the amount of fuel consumed by heating systems was determined, CO_2 emissions emitted into the atmosphere were calculated. The minimum CO_2 emissions at a base temperature of 15°C were calculated at about 1218, 1061 and 963 kg for single-, double- and triple-glazed windows, respectively. The highest rates of CO_2 emission were 2261 (for single-glazed), 1970 (for double-glazed) and 1787 kg (for triple-glazed) at a base temperature of 20°C.

Furthermore, alteration of HDD values from 2007 to 2015 was observed under the conditions of 15°C base temperature for Kocaeli. While the amount of natural gas consumed was forecasted to be 1966, 1713 and 1554 m^3 in 2011 in case single, double, or triple-glazed window is utilized, respectively, the amount of natural gas consumed was estimated to be 1225, 1067 and 968 m^3 in 2014. Between 2007 and 2015, due to severe climatic conditions, the highest CO_2 emission revealed in 2011 as 4895 kg in case single-glazed windows were employed.

Two heating systems were compared in terms of economic feasibility. For an installation cost of 13500 ₺, it was concluded that, while heat pump heating system is not economically feasible for an existing house with installed natural gas, it is feasible for a newly built house.

Natural gas heating systems are employed extensively in 74 cities of Turkey. However, air-source heat pump heating systems are not recognized good enough by the great deal of consumers because it is a very new system for Turkey. The investment cost is very high because of the fact that there is no heat pump production in Turkey yet. If they are manufactured in Turkey in the near future, initial investment cost will decrease significantly. When the initial investment cost reaches a desireable level, consumers should be encouraged to use the heat pump systems in their houses; the energy consumption of the heat pump and, therefore, its carbon emissions are much less than natural gas systems due to its high efficiency.

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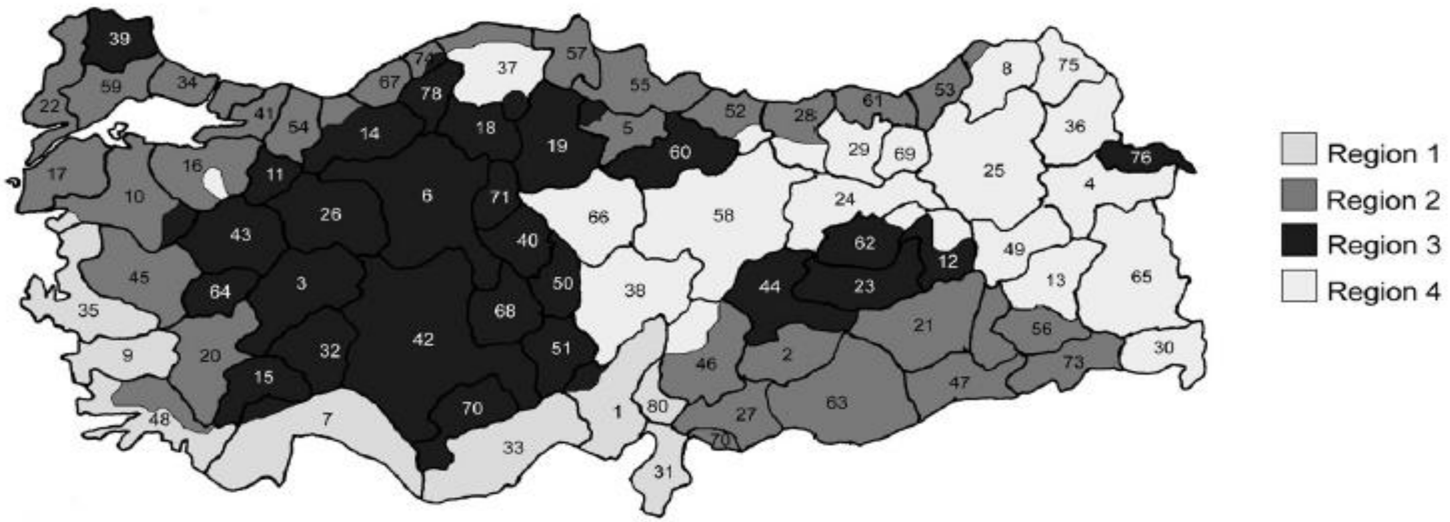
APPENDICES

Appendix A: Degree-Day regions in Turkey Identified by TS 825



1. Adana	11. Bilecik	21. Diyarbakir	31. Hatay	41. Kocaeli	51. Nigde	61. Trabzon	71. Kirikkale
2. Adiyaman	12. Bingol	22. Edirne	32. Isparta	42. Konya	52. Ordu	62. Tunceli	72. Batman
3. Afyon	13. Bitlis	23. Elazig	33. Icel	43. Kutahya	53. Rize	63. Sanli Urfa	73. Sirnak
4. Agri	14. Bolu	24. Erzincan	34. Istanbul	44. Malatya	54. Sakarya	64. Usak	74. Bartin
5. Amasya	15. Burdur	25. Erzurum	35. Izmir	45. Manisa	55. Samsun	65. Van	75. Ardahan
6. Ankara	16. Bursa	26. Eskisehir	36. Kars	46. Kahramanmaras	56. Siirt	66. Yozgat	76. Igdir
7. Antalya	17. Canakkale	27. Gaziantep	37. Kastamonu	47. Mardin	57. Sinop	67. Zonguldak	77. Yalova
8. Artvin	18. Cankiri	28. Giresun	38. Kayseri	48. Mugla	58. Sivas	68. Aksaray	78. Karabuk
9. Aydin	19. Corum	29. Gumushane	39. Kirklareli	49. Mus	59. Tekirdag	69. Bayburt	79. Kilis
10. Balikesir	20. Denizli	30 Hakkari	40. Kirsehir	50. Nevsehir	60. Tokat	70. Karaman	80. Osmaniye

Appendix B: The daily Mean outdoor Air Temperatures (^oC) in 2016

Days / Months	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
January	-5	-4	-1	4	5	10	4	4	6	8	13	16	9	4	4	12	11	1	-2	-2	4	2	-2	-3	-2	-4	2	6	6	6	8
February	9	8	10	12	7	2	2	3	4	6	11	12	15	17	18	17	14	9	8	8	4	6	10	9	10	14	13	12	15		
March	15	12	8	12	6	10	12	12	15	10	12	10	10	7	6	6	3	4	8	4	9	13	16	17	8	3	3	4	7	10	12
April	13	12	10	10	11	14	16	18	18	16	14	13	15	16	15	16	15	18	19	19	9	11	14	15	16	15	12	12	10	14	
May	14	16	15	14	10	12	14	13	16	14	16	18	22	20	19	18	15	12	12	14	15	14	15	16	17	15	14	16	16	20	22
June	21	22	20	18	18	19	18	15	15	15	17	19	20	20	20	21	22	22	24	24	24	24	24	26	24	25	24	28	22	22	23
July	23	22	24	24	22	21	28	21	18	19	20	21	24	26	22	25	25	20	18	19	22	20	20	22	23	23	24	24	25	26	
August	26	25	25	26	26	26	26	26	27	27	28	25	20	21	19	20	20	22	23	26	25	25	24	22	22	22	22	22	21	22	21
September	22	20	20	20	21	22	24	23	22	23	21	22	21	21	21	18	19	22	23	21	15	15	13	13	12	15	15	15	15	15	18
October	18	18	17	18	12	16	16	16	15	13	17	20	14	13	12	12	13	9	8	10	11	13	14	14	12	12	12	10	11	10	8
November	4	6	9	8	12	14	15	18	24	13	12	13	12	8	6	6	4	6	8	6	9	10	7	6	6	6	8	10	8	6	
December	2	6	4	2	2	1	3	1	3	5	6	4	4	0	-4	0	0	-1	-2	-2	2	2	2	4	4	4	3	2	1	2	2

Appendix B.1: Daily HDD Values at a Base Temperature of 15 °C

Months	January	February	March	April	May	June	July	August	September	October	November	December
Days	HDD (ºC-day)											
1	20	6	0	2	1	0	0	0	0	0	11	13
2	19	7	3	3	0	0	0	0	0	0	9	9
3	16	5	7	5	0	0	0	0	0	0	6	11
4	11	3	3	5	1	0	0	0	0	0	7	13
5	10	8	9	4	5	0	0	0	0	3	3	13
6	5	13	5	1	3	0	0	0	0	0	1	14
7	11	13	3	0	1	0	0	0	0	0	0	12
8	11	12	3	0	2	0	0	0	0	0	0	14
9	9	11	0	0	0	0	0	0	0	0	0	12
10	7	9	5	0	1	0	0	0	0	2	2	10
11	2	4	3	1	0	0	0	0	0	0	3	9
12	0	3	5	2	0	0	0	0	0	0	2	11
13	6	0	5	0	0	0	0	0	0	1	3	11
14	11	0	8	0	0	0	0	0	0	2	7	15
15	11	0	9	0	0	0	0	0	0	3	9	19
16	3	0	9	0	0	0	0	0	0	3	9	15
17	4	1	12	0	0	0	0	0	0	2	11	15
18	14	6	11	0	3	0	0	0	0	6	9	16
19	17	7	7	0	3	0	0	0	0	7	7	17
20	17	7	11	0	1	0	0	0	0	5	9	17
21	11	11	6	6	0	0	0	0	0	4	6	13
22	13	9	2	4	1	0	0	0	0	2	5	13
23	17	5	0	1	0	0	0	0	2	1	8	13
24	18	6	0	0	0	0	0	0	2	1	9	11
25	17	5	7	0	0	0	0	0	3	3	9	11
26	19	1	12	0	0	0	0	0	0	3	9	11
27	13	2	12	3	1	0	0	0	0	3	7	12
28	9	3	11	3	0	0	0	0	0	5	5	13
29	9	0	8	5	0	0	0	0	0	4	7	14
30	9		5	1	0	0	0	0	0	5	9	13
31	7		3		0		0	0		7		

Appendix B.2: Daily HDD Values at a Base Temperature of 16 °C

Months	January	February	March	April	May	June	July	August	September	October	November	December
Days	**HDD (ºC-day)**											
1	21	7	1	3	2	0	0	0	0	0	12	14
2	20	8	4	4	0	0	0	0	0	0	10	10
3	17	6	8	6	1	0	0	0	0	0	7	12
4	12	4	4	6	2	0	0	0	0	0	8	14
5	11	9	10	5	6	0	0	0	0	4	4	14
6	6	14	6	2	4	0	0	0	0	0	2	15
7	12	14	4	0	2	0	0	0	0	0	1	13
8	12	13	4	0	3	1	0	0	0	0	0	15
9	10	12	1	0	0	1	0	0	0	1	0	13
10	8	10	6	0	2	1	0	0	0	3	3	11
11	3	5	4	2	0	0	0	0	0	0	4	10
12	0	4	6	3	0	0	0	0	0	0	3	12
13	7	1	6	1	0	0	0	0	0	2	4	12
14	12	0	9	0	0	0	0	0	0	3	8	16
15	12	0	10	1	0	0	0	0	0	4	10	20
16	4	0	10	0	0	0	0	0	0	4	10	16
17	5	2	13	1	1	0	0	0	0	3	12	16
18	15	7	12	0	4	0	0	0	0	7	10	17
19	18	8	8	0	4	0	0	0	0	8	8	18
20	18	8	12	0	2	0	0	0	0	6	10	18
21	12	12	7	7	1	0	0	0	1	5	7	14
22	14	10	3	5	2	0	0	0	1	3	6	14
23	18	6	0	2	1	0	0	0	3	2	9	14
24	19	7	0	1	0	0	0	0	3	2	10	12
25	18	6	8	0	0	0	0	0	4	4	10	12
26	20	2	13	1	1	0	0	0	1	4	10	12
27	14	3	13	4	2	0	0	0	1	4	8	13
28	10	4	12	4	0	0	0	0	1	6	6	14
29	10	1	9	6	0	0	0	0	1	5	8	15
30	10		6	2	0	0	0	0	1	6	10	14
31	8		4		0	0	0	0		8		

Appendix B.3: Daily HDD Values at a Base temperature of 17 °C

Months	January	February	March	April	May	June	July	August	September	October	November	December
Days	HDD (ºC-day)											
1	22	8	2	4	3	0	0	0	0	0	13	15
2	21	9	5	5	1	0	0	0	0	0	11	11
3	18	7	9	7	2	0	0	0	0	0	8	13
4	13	5	5	7	3	0	0	0	0	0	9	15
5	12	10	11	6	7	0	0	0	0	5	5	15
6	7	15	7	3	5	0	0	0	0	1	3	16
7	13	15	5	1	3	0	0	0	0	1	2	14
8	13	14	5	0	4	2	0	0	0	1	0	16
9	11	13	2	0	1	2	0	0	0	2	0	14
10	9	11	7	1	3	2	0	0	0	4	4	12
11	4	6	5	3	1	0	0	0	0	0	5	11
12	1	5	7	4	0	0	0	0	0	0	4	13
13	8	2	7	2	0	0	0	0	0	3	5	13
14	13	0	10	1	0	0	0	0	0	4	9	17
15	13	0	11	2	0	0	0	0	0	5	11	21
16	5	0	11	1	0	0	0	0	0	5	11	17
17	6	3	14	2	2	0	0	0	0	4	13	17
18	16	8	13	0	5	0	0	0	0	8	11	18
19	19	9	9	0	5	0	0	0	0	9	9	19
20	19	9	13	0	3	0	0	0	0	7	11	19
21	13	13	8	8	2	0	0	0	2	6	8	15
22	15	11	4	6	3	0	0	0	2	4	7	15
23	19	7	1	3	2	0	0	0	4	3	10	15
24	20	8	0	2	1	0	0	0	4	3	11	13
25	19	7	9	1	0	0	0	0	5	5	11	13
26	21	3	14	2	2	0	0	0	2	5	11	13
27	15	4	14	5	3	0	0	0	2	5	9	14
28	11	5	13	5	1	0	0	0	2	7	7	15
29	11	2	10	7	1	0	0	0	2	6	9	16
30	11		7	3	0	0	0	0	2	7	11	15
31	9		5		0			0		9		

Appendix B.4: Daily HDD values at a base temperature of 18.3°C

Months	January	February	March	April	May	June	July	August	September	October	November	December
Days	HDD (ºC-day)											
1	23,3	9,3	3,3	5,3	4,3	0	0	0	0	0,3	14,3	16,3
2	22,3	10,3	6,3	6,3	2,3	0	0	0	0	0,3	12,3	12,3
3	19,3	8,3	10,3	8,3	3,3	0	0	0	0	1,3	9,3	14,3
4	14,3	6,3	6,3	8,3	4,3	0,3	0	0	0	0,3	10,3	16,3
5	13,3	11,3	12,3	7,3	8,3	0,3	0	0	0	6,3	6,3	16,3
6	8,3	16,3	8,3	4,3	6,3	0	0	0	0	2,3	4,3	17,3
7	14,3	16,3	6,3	2,3	4,3	0,3	0	0	0	2,3	3,3	15,3
8	14,3	15,3	6,3	0,3	5,3	3,3	0	0	0	2,3	0,3	17,3
9	12,3	14,3	3,3	0,3	2,3	3,3	0	0	0	3,3	0	15,3
10	10,3	12,3	8,3	2,3	4,3	3,3	0	0	0	5,3	5,3	13,3
11	5,3	7,3	6,3	4,3	2,3	1,3	0	0	0	1,3	6,3	12,3
12	2,3	6,3	8,3	5,3	0,3	0	0	0	0	0	5,3	14,3
13	9,3	3,3	8,3	3,3	0	0	0	0	0	4,3	6,3	14,3
14	14,3	1,3	11,3	2,3	0	0	0	0	0	5,3	10,3	18,3
15	14,3	0,3	12,3	3,3	0	0	0	0	0	6,3	12,3	22,3
16	6,3	1,3	12,3	2,3	0,3	0	0	0	0,3	6,3	12,3	18,3
17	7,3	4,3	15,3	3,3	3,3	0	0	0	0	5,3	14,3	18,3
18	17,3	9,3	14,3	0,3	6,3	0	0	0	0	9,3	12,3	19,3
19	20,3	10,3	10,3	0	6,3	0	0	0	0	10,3	10,3	20,3
20	20,3	10,3	14,3	0	4,3	0	0	0	0	8,3	12,3	20,3
21	14,3	14,3	9,3	9,3	3,3	0	0	0	3,3	7,3	9,3	16,3
22	16,3	12,3	5,3	7,3	4,3	0	0	0	3,3	5,3	8,3	16,3
23	20,3	8,3	2,3	4,3	3,3	0	0	0	5,3	4,3	11,3	16,3
24	21,3	9,3	1,3	3,3	2,3	0	0	0	5,3	4,3	12,3	14,3
25	20,3	8,3	10,3	2,3	1,3	0	0	0	6,3	6,3	12,3	14,3
26	22,3	4,3	15,3	3,3	3,3	0	0	0	3,3	6,3	12,3	14,3
27	16,3	5,3	15,3	6,3	4,3	0	0	0	3,3	6,3	10,3	15,3
28	12,3	6,3	14,3	6,3	2,3	0	0	0	3,3	8,3	8,3	16,3
29	12,3	3,3	11,3	8,3	2,3	0	0	0	3,3	7,3	10,3	17,3
30	12,3		8,3	4,3	0	0	0	0	3,3	8,3	12,3	16,3
31	10,3		6,3		0			0		10,3		

Appendix B.5: Daily HDD Values at a Base Temperature of 19°C

Months	January	February	March	April	May	June	July	August	September	October	November	December
Days	**HDD (ºC-day)**											
1	24	10	4	6	5	0	0	0	0	1	15	17
2	23	11	7	7	3	0	0	0	0	1	13	13
3	20	9	11	9	4	0	0	0	0	2	10	15
4	15	7	7	9	5	1	0	0	0	1	11	17
5	14	12	13	8	9	1	0	0	0	7	7	17
6	9	17	9	5	7	0	0	0	0	3	5	18
7	15	17	7	3	5	1	0	0	0	3	4	16
8	15	16	7	1	6	4	0	0	0	3	1	18
9	13	15	4	1	3	4	0	0	0	4	0	16
10	11	13	9	3	5	4	0	0	0	6	6	14
11	6	8	7	5	3	2	0	0	0	2	7	13
12	3	7	9	6	1	0	0	0	0	0	6	15
13	10	4	9	4	0	0	0	0	0	5	7	15
14	15	2	12	3	0	0	0	0	0	6	11	19
15	15	1	13	4	0	0	0	0	0	7	13	23
16	7	2	13	3	1	0	0	0	0	7	13	19
17	8	5	16	4	4	0	0	0	0	6	15	19
18	18	10	15	1	7	0	0	0	0	10	13	20
19	21	11	11	0	7	0	0	0	0	11	11	21
20	21	11	15	0	5	0	0	0	0	9	13	21
21	15	15	10	10	4	0	0	0	4	8	10	17
22	17	13	6	8	5	0	0	0	4	6	9	17
23	21	9	3	5	4	0	0	0	6	5	12	17
24	22	10	2	4	3	0	0	0	6	5	13	15
25	21	9	11	3	2	0	0	0	7	7	13	15
26	23	5	16	4	4	0	0	0	4	7	13	15
27	17	6	16	7	5	0	0	0	4	7	11	16
28	13	7	15	7	3	0	0	0	4	9	9	17
29	13	4	12	9	3	0	0	0	4	8	11	18
30	13		9	5	0	0	0	0	4	9	13	17
31	11		7		0	0		0		11		

Appendix B.6: Daily HDD Values at a Base Temperature of 20°C

Months	January	February	March	April	May	June	July	August	September	October	November	December
Days	HDD (ºC-day)											
1	25	11	5	7	6	0	0	0	0	2	16	18
2	24	12	8	8	4	0	0	0	0	2	14	14
3	21	10	12	10	5	0	0	0	0	3	11	16
4	16	8	8	10	6	2	0	0	0	2	12	18
5	15	13	14	9	10	2	0	0	0	8	8	18
6	10	18	10	6	8	1	0	0	0	4	6	19
7	16	18	8	4	6	2	0	0	0	4	5	17
8	16	17	8	2	7	5	0	0	0	4	2	19
9	14	16	5	2	4	5	0	0	0	5	0	17
10	12	14	10	4	6	5	0	0	0	7	7	15
11	7	9	8	6	4	3	0	0	0	3	8	14
12	4	8	10	7	2	1	0	0	0	0	7	16
13	11	5	10	5	0	0	0	0	0	6	8	16
14	16	3	13	4	0	0	0	0	0	7	12	20
15	16	2	14	5	1	0	0	0	0	8	14	24
16	8	3	14	4	2	0	0	0	0	8	14	20
17	9	6	17	5	5	0	0	0	0	7	16	20
18	19	11	16	2	8	0	0	0	0	11	14	21
19	22	12	12	1	8	0	0	0	0	12	12	22
20	22	12	16	1	6	0	0	0	0	10	14	22
21	16	16	11	11	5	0	0	0	5	9	11	18
22	18	14	7	9	6	0	0	0	5	7	10	18
23	22	10	4	6	5	0	0	0	7	6	13	18
24	23	11	3	5	4	0	0	0	7	6	14	16
25	22	10	12	4	3	0	0	0	8	8	14	16
26	24	6	17	5	5	0	0	0	5	8	14	16
27	18	7	17	8	6	0	0	0	5	8	12	17
28	14	8	16	8	4	0	0	0	5	10	10	18
29	14	5	13	10	4	0	0	0	5	9	12	19
30	14		10	6	0	0	0	0	5	10	14	18
31	12		8		0			0		12		