ASSESSMENT OF ENERGY EFFICIENCY IMPROVEMENT MEASURES IN EXISTING RESIDENTIAL BUILDINGS IN TURKEY

by

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ABSTRACT

ASSESSMENT OF ENERGY EFFICIENCY IMPROVEMENT MEASURES IN EXISTING RESIDENTIAL BUILDINGS IN TURKEY

Existing buildings are responsible for a considerable amount of global carbon emissions and energy consumptions. Improvement of existing building stock in terms of energy efficiency is needed to achieve energy and carbon saving targets. In this thesis, possible energy efficiency measures for a standard building assumed to be located in cities from each climate region of Turkey are analyzed and assessed in terms of technical and economic aspects with the purpose of investigating the saving potentials. The economic savings as well as energy and carbon savings of all the measures, investment costs and payback periods are compared with each other. According to the findings, a more feasible approach which depends on prioritization of the energy efficiency measures can be suggested for the buildings with different characteristics in different climates. Energy, carbon and cost savings potentials in each climate region and in each city which is chosen as the representative of region in this study are stated and total saving potential of Turkey's building stock is estimated. The approach proposed in this study can help decision makers to plan and evaluate their energy efficiency retrofitting strategies by guiding them to select appropriate energy efficiency measures to achieve maximum environmental and economic benefits.

ÖZET

TÜRKİYE’DEKİ MEVCUT KONUT BİNALARINDA ENERJİ VERİMLİLİĞİ İYİLEŞTİRME UYGULAMALARININ DEĞERLENDİRİLMESİ

Mevcut binalar, küresel karbon salımlarının ve enerji tüketimlerinin hatırı sayılır bir miktarından sorumludur. Mevcut bina stokunun enerji verimliliği açısından iyileştirilmesi enerji ve karbon tasarrufu hedeflerine ulaşmada gereklidir. Bu tezde; Türkiye’nin her bir iklim bölgesinden seçilen şehirlerde yer aldığı kabul edilen standart bir bina için olası enerji verimliliği uygulamaları, tasarruf potansiyellerinin araştırılması amacıyla, teknik ve ekonomik açılarla analiz edilmiş ve değerlendirilmiştir. Uygulamaların enerji ve karbon tasarruflarına ek olarak ekonomik tasarrufları, yatırım maliyetleri ve geri ödeme süreleri birbirleri ile karşılaştırılmıştır. Bulgulara göre, enerji verimliliği uygulamalarının önceliklendirilmesine dayanan daha uygulanabilir bir yaklaşım farklı iklimlerde yer alan farklı karakteristiklere sahip binalar için önerilebilir. Her bir iklim bölgesinde ve bu çalışmada temsilcileri olarak seçilen her bir şehirde enerji, karbon ve maliyet tasarrufu potansiyelleri ortaya konulmuş ve Türkiye’deki bina stokunun toplam tasarruf potansiyeli tahmin edilmiştir. Bu çalışmada önerilen yaklaşım, maksimum çevresel ve ekonomik faydaları gerçekleştirecek uygun enerji verimliliği uygulamalarını seçmede yol göstererek, karar vericilere enerji verimliliği iyileştirme stratejilerini planlama ve değerlendirmede yardımcı olabilir.

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LIST OF SYMBOLS/ABBREVIATIONS

Symbol	**Explanation**	**Unit**
k	Thermal Conductivity	W/m K
LHV	Lower Heating Value	J/kWh
q	Heat Loss	W/m^2
Ri	Inside Air Film Thermal Resistance	m^{2}K/W
Rins	Thermal Resistance of Insulation Layer	m^{2}K/W
Ro	Outside Air Film Thermal Resistance	m^{2}K/W
Rw	Total Thermal Resistance of Composite Sandwich	m^{2}K/W
Rtw	Total Thermal Resistance of Wall	m^{2}K/W
U	Overall Heat Transfer Coefficient	W/m^2 K
x	Thickness of the Insulation Material	m
η_s	Efficiency	
ρ	Density	kg/m^3

Abbreviation	**Explanation**
A	Area
AC	Alternating Current
ASHRAE	American Society of Heating Refrigerating and Air-Conditioning Engineers
BEPY	The Regulation on Building Energy Performance
CFLs	Compact Fluorescent Lamps
COP	Conference of the Parties
COP	Coefficient of Performance
DC	Direct Current
DD	Degree Days
DHW	Domestic Hot Water
DOSIDER	The Association of Natural Gas Equipment Manufacturers and Businessmen
EEA	Energy Efficient Appliances
EIA	Energy Information Agency
EIE	The General Directorate of Electrical Power Resources

	Survey and Development Administration
EPDK	Republic of Turkey Energy Market Regulatory Authority
EPS	Expanded Polystyrene
ESCO	Energy Service Company
EU	European Union
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GSHP	Ground Source Heat Pump
HVAC	Heating Ventilating and Air-Conditioning
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IRR	Internal Rate of Return
IZODER	The Association of Heat Water Acoustic and Fire Insulators
LCC	Life Cycle Cost
$LLCO_2$	Life Cycle Carbon
LPG	Liquid Petroleum Gas
NPV	Net Present Value
OECD	Organisation for Economic Cooperation and Development
PV	Photovoltaic
SEER	Seasonal Energy Efficiency Ratio
TL	Turkish Lira
TS 825	Turkish Standard 825
TUIK	Turkish Statistical Institute
UNFCCC	United Nations Framework Convention on Climate Change
VAT	Value Added Tax
XPS	Extruded Polystyrene
YEGM	The General Directorate of Renewable Energy

1. INTRODUCTION

Since the oil crisis in 1973, energy efficiency has become an important component of national strategies of countries. The main concern about “climate change” and “global warming” concepts which are consequences of greenhouse gas emissions caused mainly by fossil fuels has started in the 1980s and has gained acceleration in the 1990s. Simultaneously, during the 1980s and 1990s, energy efficiency requirements have been started to be set in most developed countries.

In 1997, governments of industrialized world gathered in Kyoto to state The Kyoto Protocol which sets carbon reduction targets for 2012. The Kyoto Protocol is an international agreement linked to the United Nations Framework Convention on Climate Change, and it commits the governments setting internationally binding emission reduction targets. The Protocol puts a heavier burden on developed countries under the principle of “common but differentiated responsibilities” since these countries are responsible for the larger amount of greenhouse gas emissions in the atmosphere. The Protocol was adopted in 1997 and entered into force in 2005. The detailed rules for the implementation adopted at The Seventh Session of the Conference of the Parties (COP 7) in Marrakesh, Morocco in 2001, and were referred to as the “Marrakesh Accords”. The Protocol’s first commitment period started in 2008 and ended in 2012. During this period, the countries committed to reduce greenhouse gas emissions to an average of 5% against 1990 levels. In Doha, Qatar, on 8 December 2012, the "Doha Amendment to the Kyoto Protocol" was adopted. According to this amendment, new commitments were defined for the Parties of the Kyoto Protocol who agreed to take on commitments in the second period from the beginning of 2013 to the end of 2020. The Countries committed to reduce greenhouse gas emissions by at least 18% below 1990 levels in the second period (United Nations Framework Convention on Climate Change, 1997).

In 2007, the report of the Intergovernmental Panel on Climate Change (IPCC) concludes that warming of the global climate system is unambiguous. The report also states that the earth is warmed by 0.74˚C over the last century, and 0.4˚C of this has occurred since the 1970s (Mitchell, 2010). The reason of this warming strongly depends on the high amount of greenhouse gas emissions which stems from anthropogenic effects. According to IPCC, for a low emissions scenario, world temperature is projected to rise by a range of 1.1 to 2.9˚C by 2090-2099 in comparison with 1980-90 while for a high emissions scenario, it increases to a range of 2.4 to 6.4˚C (Mitchell, 2010).

In the Fifth Assessment Report, IPCC demonstrates that total anthropogenic greenhouse gas (GHG) emissions have risen more rapidly from 2000 to 2010 than in the previous three decades (Intergovernmental Panel on Climate Change, 2014). From 2000 to 2010, GHG emissions grew on average by 1.0 $GtCO_2eq$ (2.2%) per year compared to 0.4 $GtCO_2eq$ (1.3%) per year over the entire period from 1970 to 2000. IPCC investigates sectors and their effects on greenhouse gas emissions. According to IPCC, GHG emissions from the buildings sector have more than doubled since 1970, accounting for 19% of global GHG emissions in 2010 (Intergovernmental Panel on Climate Change, 2014). IPCC also suggests that buildings represent a critical piece of a low-carbon future and a global challenge for integration with sustainable development. And IPCC concludes that high-performance retrofits are key mitigation strategies in countries with existing building stocks and reductions of heating/cooling energy use by 50-90% have been achieved using best practices. According to IPCC, strong evidence shows that very low-energy construction and retrofits can be economically attractive as well (Intergovernmental Panel on Climate Change, 2014).

Furthermore, IPCC states that the building sector accounts for 32% of total global final energy consumption (24% for residential and 8% for commercial), 19% of energy-related CO_2 emissions, 51% of global electricity consumption, approximately one-third of black carbon emissions, and a significant amount of F-gases (fluorinated gases) in 2010. Moreover, GHG emissions stem from buildings sector has remarkably increased between 1990 and 2010.

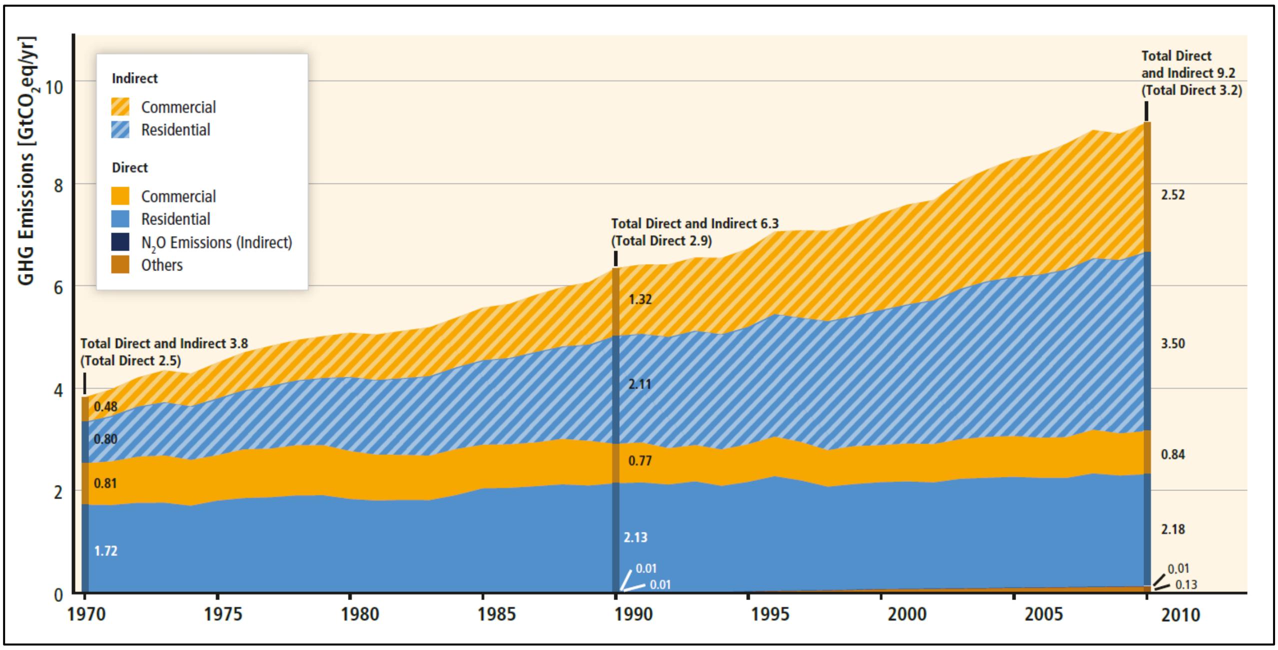

Figure 1.1. Emissions in building sector (Intergovernmental Panel on Climate Change, 2014).

And similar to emissions, annual per capita final energy use of residential and commercial buildings has grown among the two decades between 1990 and 2010 in most world regions (Intergovernmental Panel on Climate Change, 2014). Turkey is one of the countries that have the highest amount of energy consumption in buildings among rest of the world.

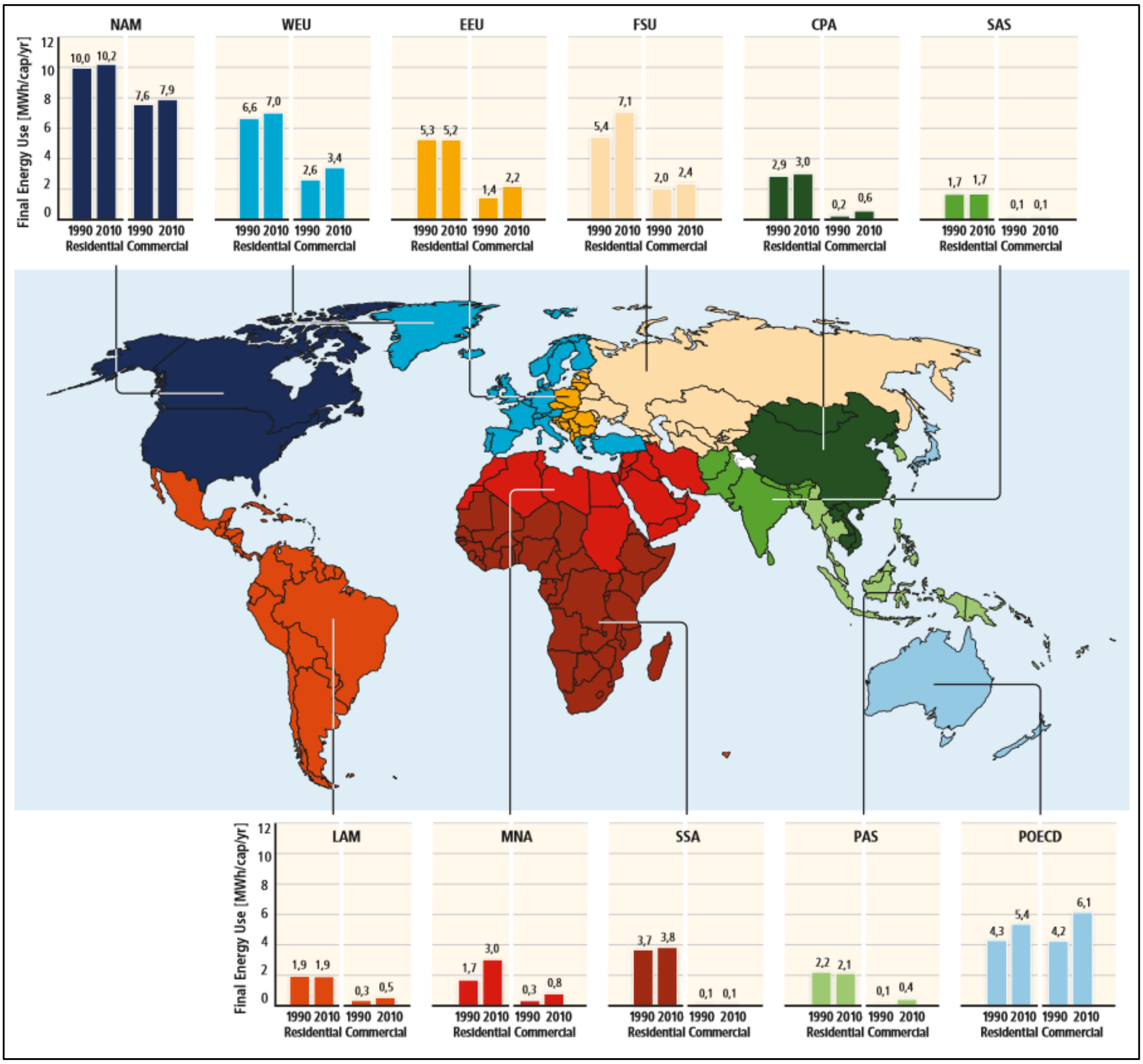

Figure 1.2. Annual final energy use of residential and commercial buildings per capita (Intergovernmental Panel on Climate Change, 2014).

From 1990 to 2007, world's energy consumption increased by 31%, electricity consumption increased by 60% and CO_2 emissions increased by 31%. Likewise, Turkey's energy consumption increased by 94% from 1990 to 2007. Turkey's energy demand has increased by 4.3% per year from 1990 to 2008, which is three times larger than that of the world average. Similarly, Turkey had the second largest growth rate of electricity (7.1% per year since 1996) and natural gas demand in the world, after China, since 2000 (Ceylan, 2010).

In 2008, the European Union (EU) Commission put some targets which are called 20-20-20 targets to be met by 2020 to transform into an energy efficient and low carbon economy. These targets are (a) a reduction in EU greenhouse gas emissions of at least 20% below 1990 levels, (b) 20% of EU energy consumption to come from renewable sources and (c) a 20% reduction in primary energy use compared with projected levels, to be achieved by improving energy efficiency (Ceylan, 2010).

In the recent decades all countries experienced an increase in energy prices. Yet, for last a few years, Turkey is in the first three among other countries. In 2003 Turkey has only 83.3 index value for energy, whereas she has 184.7 index value in 2011 (Organization for Economic Co-operation and Development, 2012). This implies that energy prices in Turkey have increased nearly two times from 2003 to 2011. Table 1.1 shows the consumer price index values of some countries for 2009, 2010 and 2011.

Table 1.1. Consumer price index (2005=100) for energy (Organization for Economic Co-operation and Development, 2012).

country	**2009**	**2010**	**2011**
Turkey	152.1	168.2	184.7
non-OECD member economies (South Africa)	146.7	169.3	201.4
OECD Europe	120.3	129.4	143.9
OECD Total	114.4	123.3	138.3
United States	109.1	119.4	137.8

According to U.S. Energy Information Administration’s (EIA) International Energy Outlook 2011 report, world’s energy consumption is expected to increase by 53% from 2008 to 2035. Also, the projections of EIA for 2035 states that fossil fuels are going to be the largest supplier of the energy used in the world even if the share of renewable energy increase. Both natural gas and coal consumption will increase while petroleum based fuel’s consumption will decrease as well. Similarly, EIA claims that world’s electricity generation will increase by 85% from 2008 to 2035 and mostly used fuel type will be still fossil fuels (U.S. Energy Information Administration, 2011). World’s electricity generation by fuel type is shown in the figure below.

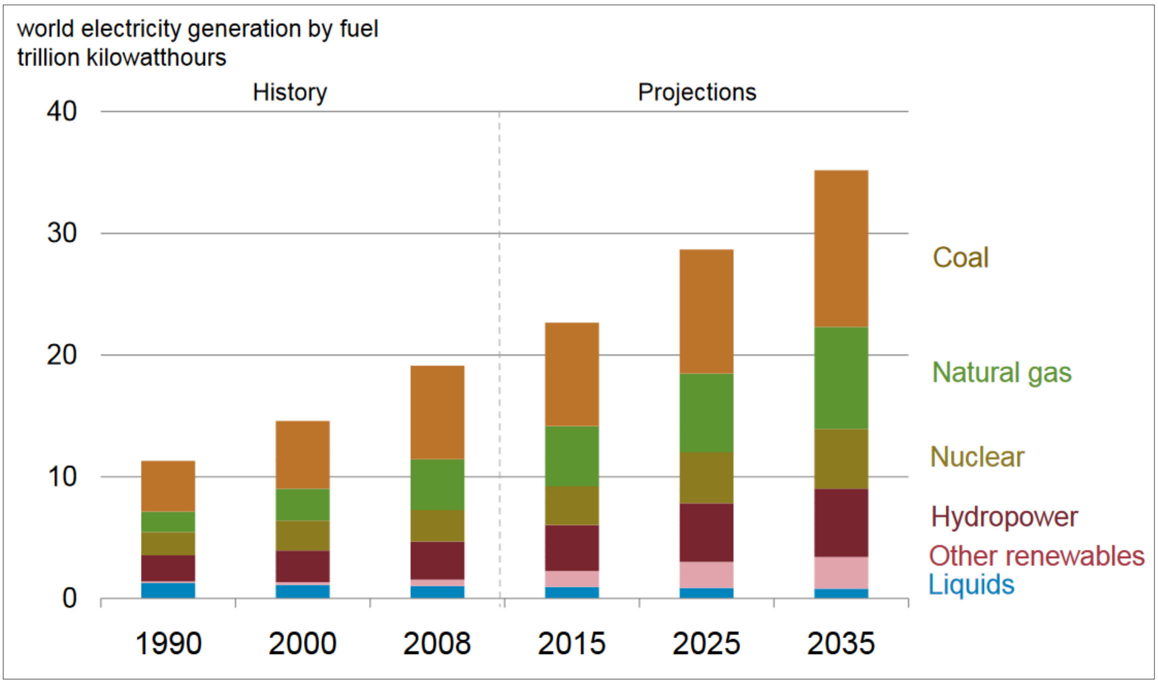

Figure 1.3. World's electricity generation by fuel type (U.S. Energy Information Administration, 2011).

The U.S. Energy Information Administration predicts world energy related CO_2 emissions will rise by 43% from 2008 to 2035. And coal will account for the largest share of CO_2 emissions (U.S. Energy Information Administration, 2011). According to EIA's 2035 scenario, world residential energy use will increase by 1.1% per year, from 52 quadrillion Btu in 2008 to 69 quadrillion Btu in 2035 (U.S. Energy Information Administration, 2011). Especially in developing countries, increasing economic growth, population and improving living standards will bring higher demand for residential energy.

The energy consumption of buildings in the European Union is about 40% of the total demand. Similarly, buildings consume 40% of the materials entering the global economy and generate 40-50% of the total emission of greenhouse gases (Ardente et al., 2011). In the United States, residential and commercial buildings use more than two-thirds of electricity generated and account for 36% of natural gas and nearly 40% of energy use (International Energy Agency, 2008b; U.S. Department of Energy, 2008). These facts show the need for efficient design and construction of buildings in the world. Energy consumption in different sectors is analyzed in the Information Paper of International Energy Agency (IEA) in 2008 (International Energy Agency, 2008a). According to this report energy consumption breakdown by sectors is shown in Figure 1.4. Figure 1.4 shows that residential sector has a great contribution to the total energy consumption. What is more, International Energy Agency (IEA) states that only existing buildings are responsible for over 40%

of the world's total primary energy consumption, and account for 24% of world's CO_2 emissions (International Energy Agency, 2008b). Figure 1.5 shows the energy consumption breakdown of sectors in Turkey.

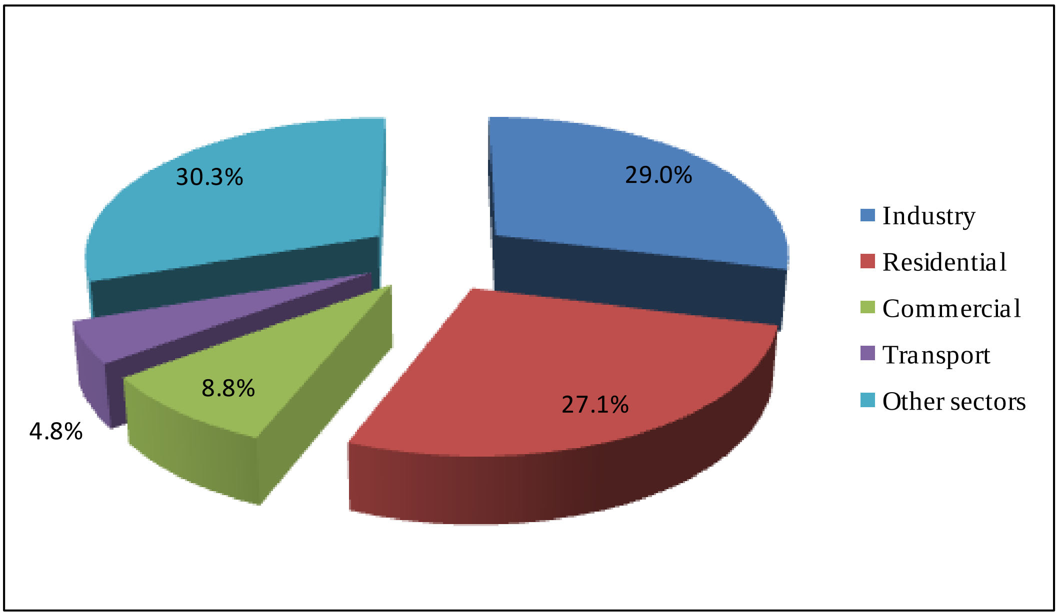

Figure 1.4. Energy consumptions of different sectors (International Energy Agency, 2008a).

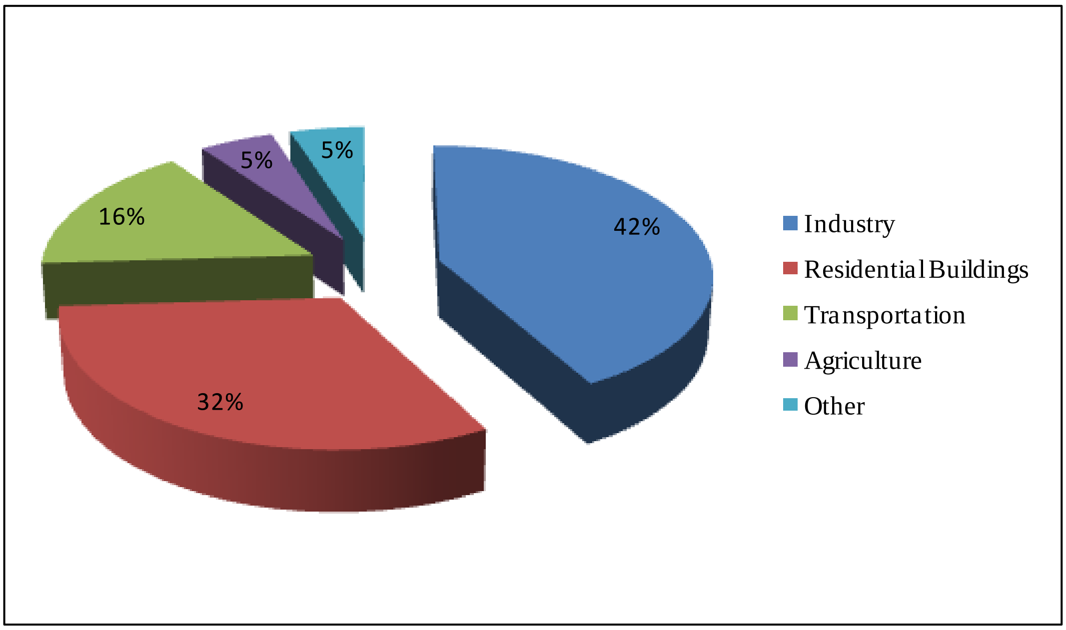

Figure 1.5. Energy consumption breakdown in Turkey (Arıman, 2008).

Similar to the rest of world, residential sector itself has a huge effect on the national energy consumption in Turkey. Hence, a significant amount of energy would be saved just by improving homes in terms of energy efficiency.

Furthermore, Ardente et al. (2011) states that the operation phase of buildings accounts for the majority of the energy consumption in the building life time rather than the production/construction and demolition phases (Ardente et al., 2011). He implies that the results of a recent analysis of a building showed that the use phase consumes the significant amount of energy which is 75%, the construction phase consumes 19% of the energy demand and the maintenance and end life phases accounts for 6% of the total energy demand (Ardente et al., 2011).

According to IPCC, measures to reduce greenhouse gas emissions from buildings can be categorized into three: (a) reducing energy consumption, (b) switching to low-carbon fuels and utilizing renewable energy and (c) reducing the emissions of non-CO_2 greenhouse gas emissions (Intergovernmental Panel on Climate Change, 2007). IPCC emphasizes that most cost-effective GHG emission reduction option is improving energy efficiency of both new and existing buildings. Cost effective energy efficiency technologies that can be utilized in buildings are passive solar design, efficient lighting and household appliances, efficient ventilation and cooling systems, solar water heating and insulation (Intergovernmental Panel on Climate Change, 2007). According to IPCC, when several technologies such as high performance windows, glazing, phase change material to increase the buildings thermal mass and high performance systems like reversible heat pumps combined with passive solar technologies and passive design techniques, 80% of energy consumption reduction can be achievable (Intergovernmental Panel on Climate Change, 2007).

So far attempts to improve the energy performance of the building sector and hence residential building sector mainly have been paid attention to new buildings. Most of European countries have succeeded in reducing energy consumption of new residential buildings by more than 50% without increasing their building cost. These buildings represent about 20% of the building stock but consume only 5% of energy (Zavadskas et al., 2008). Similarly, Hens et al. (2001) argues that it takes at least 70 years before most of the housing stock in a country renewed, for this case; the impact of energy efficient new construction on the CO_2 release seems quite marginal if the period considered does not extend beyond a decade. According to him, this effect becomes significant only over a longer period, on condition that more stringent energy efficiency measures are combined with a shift from new construction to retrofit and improvement actions (Hens et al., 2001). Another study on a comparison of demolishing non-efficient existing buildings and then building efficient ones with renovating existing buildings shows that retrofitting existing buildings is a more cost and energy efficient action (Hong et al., 2007). IPCC also states that largest portion of carbon savings potential is in retrofitting existing buildings as buildings are very long-lived and a large proportion of the total building stock existing today will still exist in 2050 (Intergovernmental Panel on

Climate Change, 2014, Intergovernmental Panel on Climate Change, 2007). Harvey (2009) states that the reduction in the energy intensity (annual energy use per unit floor area) of existing buildings by factors of two or three can be achieved through comprehensive renovations (Harvey, 2009). All of the abovementioned arguments prove the importance and urgency of the energy efficiency retrofit of existing building stock to decrease energy consumption levels and so greenhouse gas emissions.

Considering Turkey’s high dependence on foreign energy sources, similar issues are also valid for Turkey. Turkey is heavily dependent on imported energy sources like oil, natural gas and coal which bring a great cost on both national economy and air pollution. Turkey imports a higher portion of its energy demand. Its energy import is 28.5 million tons of oil equivalent in 1990 and it has reached to 54.4 million tons of oil equivalent in 2000 and it is expected to increase to 228.2 million tons of oil equivalent which is 76% of total energy supply in 2020 (Öztürk et al., 2005). According to Turkish Statistical Institute’s (TUIK) last research on existing buildings in Turkey in 2000, there are nearly 8 million building stock and approximately 16 million residential unit stock which do not even have any insulation, needs a very basic and well known energy efficiency requirement (Türkiye İstatistik Kurumu, 2004). Hence, concentration on improving the building stock has greater potential and more attention should be paid to improve the existing building stock. Considering her huge building stock, Turkey would greatly benefit from energy efficient retrofit of existing buildings.

Energy requirement of buildings is directly linked to climatic conditions. Climatic conditions affect the energy consumption for optimum indoor temperature, building design and building materials to be chosen. Energy savings in buildings can be achieved through (a) a better and improved shape, form and building envelope, (b) improved energy efficiencies of devices and household appliances, (c) alternative energy systems and operations of buildings, (d) using renewable energy technologies and (e) changing occupant behavior. Energy consumption breakdown of residential buildings according to International Energy Agency is shown in Figure 1.6. A considerable amount of energy is consumed for heating in order to achieve thermal comfort conditions in the buildings. Additionally, water heating, appliances, lighting and cooking are the other main energy consuming items in residential buildings. Hence, energy efficiency measures should be taken by giving priority to the abovementioned energy consuming systems.

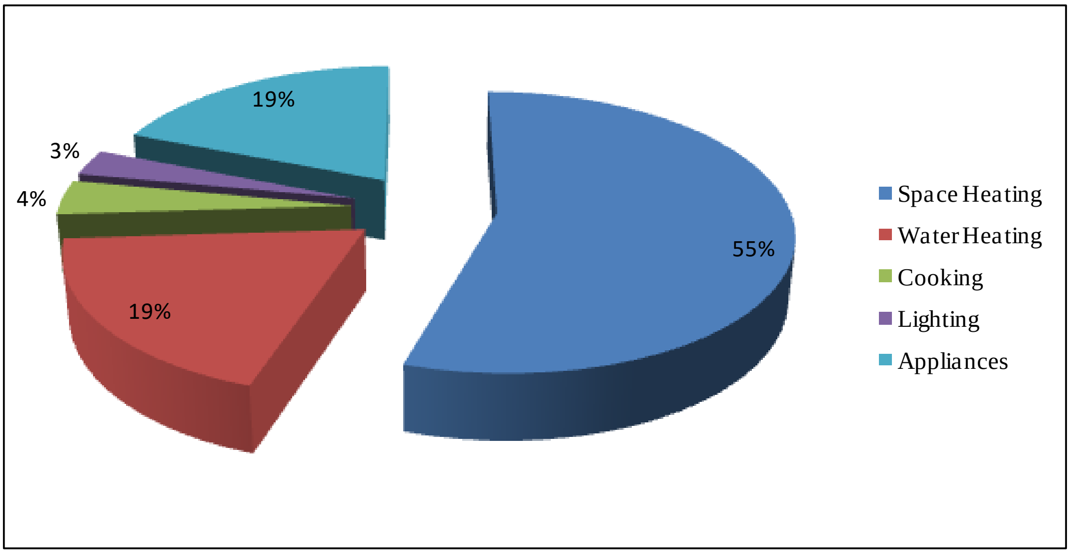

Figure 1.6. Energy consumption by use (International Energy Agency, 2008b).

According to IPCC, space heating represents 32-34 % of the global final energy consumption in both the residential and the commercial building sub-sectors in 2010. Lighting is very important for commercial sector, while cooking and water heating are significant end-uses in residential sector (Intergovernmental Panel on Climate Change, 2014).

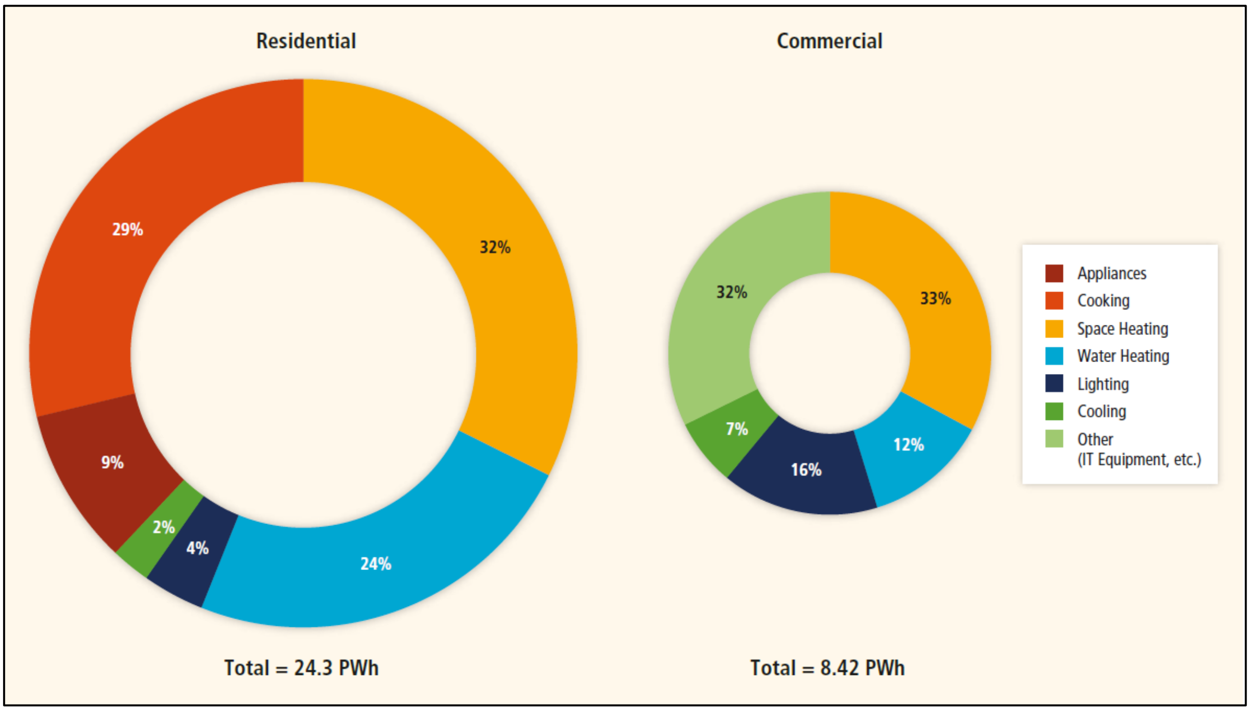

Figure 1.7. World’s building final energy consumption by end-use in 2010 (Intergovernmental Panel on Climate Change, 2014).

According to a research in the United Kingdom which tries to predict the CO_2 emissions of the existing English housing stock concludes that, the space heating accounts for 53%, water heating for 20%, cooking for 5% and lights and appliance for 22% of CO_2 emissions of a house (Firth et al., 2010). Similarly, International Energy Agency states that the energy requirement for heating, cooling, ventilation and the preparation of domestic hot water is approximately 75% of a residential building's total energy demand (International Energy Agency, 2008a). Energy use breakdown of residential sector in the Unites States of America and China are shown in Figure 1.8 and Figure 1.9. The largest energy using activity is space heating in both countries. Space heating is followed by water heating in China and by appliances in the Unites States. Lighting and cooking are the other most energy consuming activities in the residential buildings of these countries.

Energy efficiency can be achieved through environmentally friendly and cost-effective technologies which will at the end lead to a significant greenhouse gas emission reduction. These technologies may include passive solar design, high efficient lighting and appliances, high efficient ventilation and cooling systems, solar water heating systems, insulation materials and techniques, building materials and multiple glazing. A significant portion of these savings can be achieved in ways that reduce life-cycle costs, thus providing reductions in CO_2 emissions that have a net benefit rather than cost. However, due to the long lifetime of buildings and their equipment, as well as the strong and numerous market barriers prevailing in this sector, many buildings do not apply the aforementioned that will provide life-cycle cost minimization.

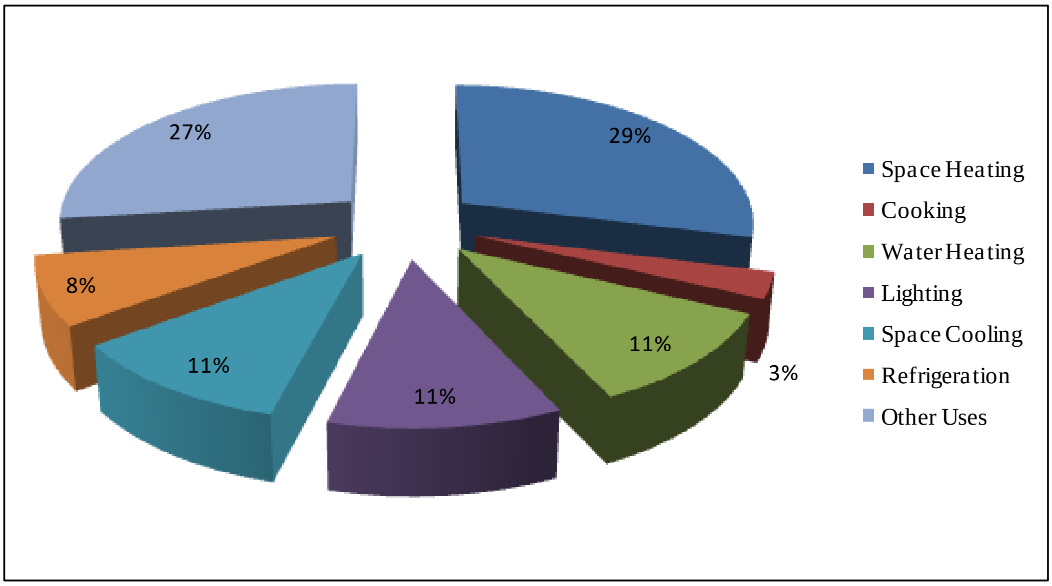

Figure 1.8. Energy use breakdown of residential buildings in the United States (Intergovernmental Panel on Climate Change, 2007).

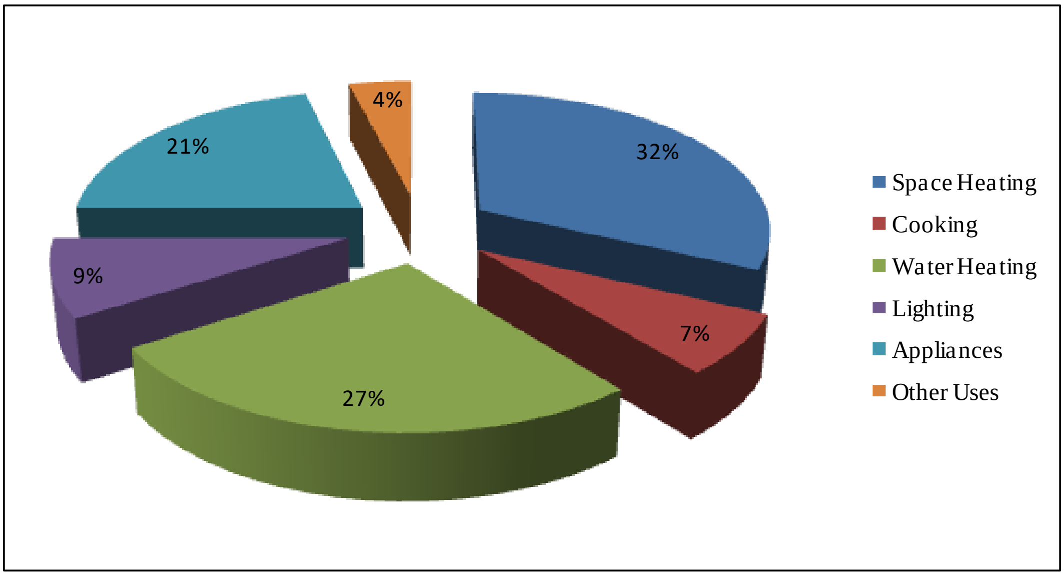

Figure 1.9. Energy use breakdown of residential buildings in China (Intergovernmental Panel on Climate Change, 2007).

Figure 1.10 shows the low cost mitigation measures that could result in the reduction of greenhouse gases in Turkey. Besides changes in consumer behaviors, key aspects are the use of energy efficient appliances and solar energy as well as improving insulation in buildings.

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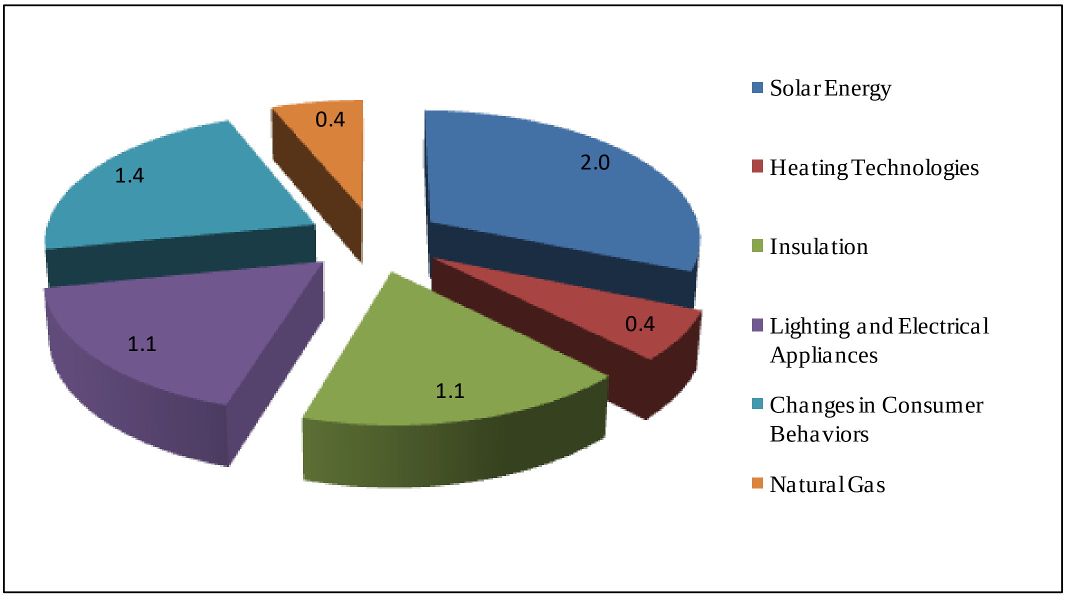


Figure 1.10. The low cost mitigation measures in Turkey (MT CO_2-eq) (Onaygil, 2010).

Many of the developed and developing countries have taken regulatory measures, have passed laws, regulations, building codes, standards, action plans, strategies and created market mechanisms to deal with energy efficiency, emission reduction and buildings. One of them is EU Energy Efficiency Action Plan which was first published in 2000. In 2006, EU Energy Efficiency Action Plan dealt with energy efficiency possibilities in all sectors, including appliance efficiency standards, energy labeling and building performance (European Union, 2006). The plan identifies the residential buildings sector as holding the largest cost-effective savings potential, due to its substantial share of total energy consumption. The full energy saving potential in this sector is estimated to be 27% by 2020 (International Energy Agency, 2008b). According to EU Energy Efficiency Action Plan published in 2011, the greatest energy saving potential lies in buildings. The plan focuses on ways to increase attention the renovation process in public and private buildings and to improve the energy performance of the appliances used in them. It also states that public sector should have a leading role and should increase the refurbishment rate of public buildings (European Union, 2011). EU Directive on the Energy Performance of Buildings is first adopted in 2002 and then revised in 2008. The directive introduces a calculation methodology of energy performance of both new and existing buildings and sets standards for member states to reach. The directive also introduces an energy performance certificate for buildings which shows their energy performance level (European Union, 2002). The 2010 Energy Performance of Buildings Directive and the 2012 Energy Efficiency Directive are the EU's last and main legislation about reducing the energy consumption of buildings. According to the Energy Performance of Buildings Directive; all new buildings must be nearly zero energy buildings by 31 December 2020 and all public buildings must be nearly zero energy buildings by 31 December 2018. Additionally, EU countries must set minimum energy performance requirements for new buildings, for the major renovation of buildings and for the replacement or retrofit of building elements (European Union, 2010). According to the Energy Efficiency Directive; EU countries make energy efficient renovations to at least 3% of buildings owned and occupied by central government, these countries should only purchase buildings which are highly energy efficient and must draw-up long-term national building renovation strategies which can be included in their National Energy Efficiency Action Plans (European Union, 2012).

ASHRAE 90.1 is another standard for building energy efficiency which is developed by the United States Department of Energy - Building Energy Codes Program (American Society of Heating Refrigerating and Air-conditioning Engineers, 2016). It provides minimum requirements for energy efficiency of buildings except low-rise residential buildings and covers calculations and appropriate applications for building envelope, heating, ventilating and air conditioning systems and also for water heating and lighting. According to this standard, the Unites States is divided into different climate zones, and different specifications such as insulation thickness are forced to buildings in these zones.

Energy efficiency efforts in Turkey have begun in 1980s and have gained acceleration in 2000s. These efforts are usually focused on industry and building sectors as well as lighting, appliances and transportation. To improve energy efficiency, Turkey usually acts in accordance with the European Union. Regulatory actions and laws in energy efficiency have gained attention in recent years. One of the responsible parties of energy efficiency in Turkey is The General Directorate of Renewable Energy (YEGM) and it has formed with reorganization of former The General Directorate of Electrical Power Resources Survey and Development Administration (EIE), in November 2011. The General Directorate of Electrical Power Resources Survey and Development Administration (EIE), an agency under the administration of The Ministry of Energy and Natural Resources, is responsible for researching and promoting energy efficiency, development of measures and conducting activities on renewable energy sources and energy efficiency area. Another responsible party of energy efficiency in buildings sector is The Ministry of Environment and Urbanization that also develops national climate change action plans and national greenhouse gas monitoring network. The Ministry of Science, Industry and Technology is the other responsible actor in energy efficiency requirements of energy related products and equipment.

Turkey became signatory to the United Nations Framework Convention on Climate Change (UNFCCC) in 2003 following the approval of Law No. 4990 permitting the signing of the Framework Convention on Climate Change in 2003. In 2009, Turkey approved the Law on joining Kyoto Protocol of United Nations and became a party to the Protocol. Turkey is an Annex I Party of the UNFCCC similar to other OECD countries. However, Turkey has no obligations about setting emission reductions targets under the Protocol since it is not an Annex B country as being a developing country.

Energy Efficiency Law (Official Gazette 02.07.2007, no: 26510) was passed in 2007 to demonstrate a national energy efficiency policy, with an aim of to increase efficiency in using energy sources and energy as to use energy effectively, to utilize renewable energy and to reduce waste in order to ease the burden of energy costs on the economy and protect environment (Enerji Verimliliği Kanunu, 2007). The law aims to provide an institutional framework for energy efficiency in buildings sector by including (a) to implement minimum energy performance standards, (b) to issue energy identity certificate for buildings, (c) to appoint energy managers for public and commercial buildings and (d) to install individual heat meters for central heating systems in buildings (Enerji Verimliliği Kanunu, 2007). This measure was followed with the enactment of the Regulation on Efficient Utilization of Energy Sources (Official Gazette 25.10.2008, no: 27035) (Enerji Kaynaklarının ve Enerjinin Kullanımında Verimliliğin Arttırılmasına Dair Yönetmelik, 2008). This regulation came into force in 2008 and revised in 2011 and it includes standards for energy efficiency consulting companies, energy managers and energy efficiency programs for public entities and also provides requirements about energy labelling of household appliances and other equipment. The regulation covers commercial and service buildings having either 20000 m^2 or more construction area or 500-ton oil equivalent (toe) or more total energy consumption annually as well as governmental buildings with either 10000 m^2 or more construction area or 250 toe or more total energy consumption annually.

Furthermore, in scope of building insulation, TS 825 standard on “thermal insulation rules of buildings” is first adopted in 1985, then it is revised and put to force in 2000 and updated in 2008 (Türk Standartları Enstitüsü, 2008). This standard governs the thickness of thermal insulation material that should be applied to buildings; TS 825 is an application of ‘‘ISO 9164-Thermal insulation calculation of space heating requirements for residential buildings” in every respect and basically similar to EN 832-Thermal performance of buildings calculation of energy use for heating residential buildings. In accordance with the standard, “Regulation on Thermal Insulation of Buildings” (Official Gazette 08.05.2000, no: 24043 and Official Gazette 09.10.2008, no: 27019) is put to force in 2000 and updated in 2008 (Binalarda Isı Yalıtım Yönetmeliği, 2008). The standard and regulation are obligatory for all new buildings to be built after June 14th 2000. Moreover, The Ministry of Industry and Trade published announcements on household electrical appliances labeling standards for light bulbs, washing and drying machines, electrical ovens in 2002, for fluorescent lamps, air conditioners, refrigerators and freezers in 2006 (Ceylan, 2010).

The Regulation on Building Energy Performance (BEPY) (Official Gazette 05.12.2008, no: 27075) was enacted in 2008 and then revised in 2010 and 2011 (Binalarda Enerji Performansı Yönetmeliği, 2008). The regulation aims to minimize energy use of buildings by this way to prevent energy loss and to protect the environment. The regulation refers to TS 825 standard for the rules on heat loss from building envelope and it states minimum requirements for heat loss and general rules for design and orientation of buildings, insulation, heating, ventilation and air conditioning systems, hot water systems, lighting, renewable energy usage and energy performance certificate. The regulation is developed from European Union’s Energy Performance of Buildings Directive. The regulation covers both existing and newly constructed residential, commercial and governmental buildings with at least 2000 m^2 of usage area. This regulation forces to obtain an “Energy Performance Certificate” of at least C grade according to calculated energy class for all new buildings from 2011 onwards. And also existing buildings must obtain an “Energy Performance Certificate” of A-G class until 2017. The process aims to provide energy performance labels for buildings ranging from A (most efficient) to G (least efficient) and each label represents a proportional energy use reduction on a baseline “typical” building. The certificate includes information about the thermal and overall energy efficiency of building, energy performance classification (A-G) and related emissions. The energy performance is verified by bespoke software called Building Energy Performance Software (BEPTR) which is developed to benchmark performance for various building typologies on a like-for-like basis and all new buildings are expected to achieve at least a minimum rating of C in order to qualify for a building permit. The software simulates the building performance and determines the reduction or increase of energy and greenhouse gas emission on the baseline. The software is internet-based and the information entered is stored in a central database under the control of the Ministry of Environment and Urbanization. This system, intends to create a detailed tracking system and database of buildings for Turkey. The software calculates and evaluates the energy performance of houses, offices, educational buildings, healthcare facilities, hotels and shopping and commercial centers. Information about energy consuming systems of a building such as heating, cooling, hot-water, lighting and ventilation is entered into the software as input. The results of the calculations of the actual building’s energy performance are compared and proportioned with that of the reference building. According to the obtained ratio, the building’s energy class is determined. The reference building is identical to the proposed design in terms of location and climate data, geometry, building envelope, electrical and mechanical systems, lighting system, hot water system, cogeneration system and renewable energy.

The Regulation on Eco-design Requirements for Energy Related Products (Official Gazette 07.10.2010, no: 27722) was enacted in 2010 in order to state minimum energy performance standards and to increase the usage of energy efficient appliances such as refrigerators, freezers, washing machines, dishwashers and so forth (Enerji ile İlgili Ürünlerin Çevreye Duyarlı Tasarımına İlişkin Yönetmelik, 2010). Likewise, the Regulation on Indication by Labelling and Standard Product Information of the Consumption of Energy and Resource by Products (Official Gazette 02.12.2011, no: 28130) was enacted in 2011 (Ürünlerin Enerji ve Diğer Kaynak Tüketimlerinin Etiketleme ve Standart Ürün Bilgileri Yoluyla Gösterilmesi Hakkında Yönetmelik, 2011). The regulation requires energy labels for household appliances to increase the awareness of end-users about energy efficiency.

In 2011, “National Climate Change Action Plan 2011-2023 in Turkey” is published (Türkiye Cumhuriyeti Çevre ve Şehircilik Bakanlığı, 2012). Targets and goals against climate change for many sectors are set in this action plan. One of these sectors is the building sector. The main target to be reached till 2023 is to increase the utilization of renewable energy in buildings. Another target is to be able to provide “energy label” for all buildings till 2017. Afterwards, “Energy Efficiency Strategy Paper 2012-2023” (Official Gazette 25.02.2012, no: 28215) is published by The Ministry of Energy and Natural Sources (Türkiye Cumhuriyeti Enerji ve Tabii Kaynaklar Bakanlığı, 2012). The paper aims to determine a framework for Turkey’s energy efficiency policy and to set main targets and related actions to achieve its goals. In this document, the amount of energy per GDP, namely energy density of Turkey in 2023 is aimed to be decreased by 20% than that of in 2011. One of the seven strategic purposes set in scope of this aim directly points buildings whereas another one indirectly address building sector. The former one, which is “Strategic Purpose-2”, is “to decrease energy demand and carbon emissions of the buildings and to promote sustainable environment friendly buildings using renewable energy sources”. The latter one, which is “Strategic Purpose-3”, is “to provide market transformation of energy efficient products”. One of the strategic target of “Strategic Purpose-2” is to make at least one fourth of the building stock in 2010 sustainable till 2023. The other strategic target of “Strategic Purpose-2” is about requiring heat insulation and energy efficient heating systems for certain existing buildings by 2023.

The Tenth Development Plan (2014-2018) is approved in 2013 and it states transformation programs called “Domestic Resource Based Energy Production Program” and “Energy Efficiency Improvement Program” (Türkiye Cumhuriyeti Kalkınma Bakanlığı, 2014). The latter program targets to reduce Turkey’s primary energy intensity to 0.243 toe/1000 dollars at the end of 2018 and to reduce energy consumption of public buildings by 10% until 2018. One of the component of the program is about “improving energy efficiency in buildings” and it includes (a) disseminating energy efficiency investments in public buildings by various financing methods including energy performance contract (EPS) borrowing model that allows debt repayment with savings obtained after project implementation and (b) converting the external structures surrounding the buildings and the heating systems in old buildings with low and/or insufficient insulation to thermally insulated ones, which also meet the current standards.

Most recently, Turkey signed the agreement of the UNFCCC 21st Conference of the Parties (COP21) meeting in Paris held on April 22nd, 2016, and became a party of the Paris Agreement. According to this agreement, signatory countries are asked to submit their own intended Nationally Determined Contribution. Turkey submitted its intended nationally determined contribution in the form of reduction from increase namely 21% reduction in GHG emissions from the business-as-usual level during 2020-2030 (Türkiye Cumhuriyeti Çevre ve Şehircilik Bakanlığı, 2016). Turkey’s Nationally Determined Contribution includes both quantitative and qualitative targets in emissions, energy production and energy consumption.

In addition to obligatory policies and measures, there are also voluntary systems for energy efficiency of buildings. One of them is Energy Star Program. It is a joint program of the U.S. Environmental Protection Agency and the U.S. Department of Energy in order to protect the environment through energy efficient products and practices. Energy Star is introduced in 1992 as a voluntary labeling program. It usually gives labels to office equipment products, residential heating and cooling equipment and also appliances, lighting, home electronics. Energy Star has also started to label new homes and commercial and industrial buildings (U.S. Environmental Protection Agency, 1992). Other voluntary systems for energy efficiency of buildings are green buildings certification systems. Many developed and developing countries have their own national or international green building certifications schemes such as LEED from the Unites States, BREEAM from the United Kingdom, DGNB from Germany, CASBEE from Japan, Green Star from Australia and so forth. Some of the schemes of the abovementioned certification systems are focused on existing buildings such as LEED-EB, BREEAM In-Use, CASBEE-EB. Most well-known international green certification systems are LEED and BREEAM (U.S. Green Building Council, 2000; Building Research Establishment, 1990). LEED is widespread through the continental America whereas BREEAM is widespread in the Europe. Both of them aim to reduce energy consumption of the both new and existing buildings and provide sustainable and better living area for building occupants as well as the environment through consuming less energy and water, emitting less CO_2 and reducing waste generated. These building certification schemes provide an explicit and consistent structure for the documentation and third-party review of strategies, policies, and performance in order to reduce their energy and water consumptions and emissions. These systems have formally been implemented in Turkey since 2008; prior to which, a few buildings with green features were constructed, but never officially certified or verified by third parties. The first building to achieve formal LEED certification was the Unilever Headquarters building in Istanbul, a 7000 m^2 commercial interior project. Since then, a total of 463 projects are registered, but only 206 projects have been certified as of 11th March 2017, under the abovementioned international green building systems, a majority of which target a LEED rating.

Another voluntary certification system is Passive House which is developed by the Passive House Institute, an independent research institute founded in 1996 in Germany. The main requirements for this building standard are as follows: (a) space heating demand must not to exceed 15 kWh/ m^2 of net living space per year or 10 W/ m^2 peak demand, (b) renewable primary energy demand in other words total energy to be used for all domestic applications (heating, hot water, electricity) must not exceed 60 kWh/m^2 of net living space per year, (c) airtightness must be a maximum of 0.6 air changes per hour at 50 Pascals pressure and (d) thermal comfort must be met for all living spaces during winter and summer, with not more than 10% of the hours in a given year over 25˚C (Passive House Institute, 1996).

Another important instrument in energy efficiency is Energy Service Companies (ESCO). ESCO concept is first introduced by the Unites States in the early 1980s and become a useful market mechanism in order to reduce and manage energy consumption. ESCOs are private sector companies that provide energy and emission improvements via energy efficiency and emission reduction projects which may be turn-key projects. These companies finance or assist financing energy projects with providing guarantee of reduction or improvement to its clients. They deliver energy improvements under an “energy performance contract”. The ESCOs create their own income from the cost savings and renewable energy produced during the implementation of the energy projects (Okay and Akman, 2010). In the U.S. and Europe, ESCOs are actively utilized in building renovation. They provide energy efficiency advisory to building owners and inhabitants on energy efficient retrofitting and offer financing. Not all ESCOs, but some of them target residential buildings sector. ESCOs have started to be developed in Turkey in recent years, yet they are not as active as the ones in developed countries.

The potential benefits from implementing energy efficiency retrofits to residential buildings are huge. First of all, from the environmental point of view, limiting energy use in buildings reduces greenhouse gas emissions and thereby reduces effects of climate change and also reduces pollution produced by the combustion of fossil fuels. The environmental benefits appear on two scales, local and global. Because much of buildings' demand for energy requires local energy combustion in individual heating systems or district heating, reduced energy demand improves air quality at the local level. In larger scale, a reduced demand for energy requires fewer power plants, thereby delaying or impeding the construction of new power plants and provide devoting public funds elsewhere (International Energy Agency, 2008a).

However, implementing energy efficiency and emission reduction measures in buildings provide co-benefits such as other economic and social benefits besides the environmental benefits. Creating of jobs and new markets, new business opportunities, energy security and economic competitiveness in macro level are some of the economic benefits associated with the energy efficient measures. At the level of the individual home, an energy efficiency retrofit can reduce energy bills of the inhabitants by twenty to forty per cent while increasing the comfort and livability of the home (LeBaron and Rinaldi, 2010). At the national level, energy efficiency retrofits implemented at a large scale substantially reduce the nation's carbon footprint. By reducing energy consumption of building stock, a nation can reduce dependence on imported energy and thereby strengthen its compatibility. Social benefits include increased habitant comfort in homes, better social welfare for low income communities because of reduced energy payments since inhabitants pay less to fuel and electricity, better air quality and healthier living spaces, all in all better quality of life for everybody.

Turkish residential sector has a great potential for carbon emissions reductions through the use of both energy efficient improvements and renewable energy technologies. However, the residential sector is complex since making a change needs to face some technical, social and economic barriers. The complexity of the residential buildings arises from the differences in the physical characteristics of the buildings, variations in the climatic zones of a country and the differences in the habitual behaviors of the occupants. Because of the lack of a certain building and energy efficiency regulation in Turkey for years, the existing residential building stock shows great variations in the size, shape, construction material and techniques. According to occupant behavior, hot water usage, lighting and household appliances offer variations, as well. The geographical regions of Turkey differ from each other in technical, cultural and habitual characteristics. Therefore, a deep understanding of the nature of the energy consumption in Turkish residential buildings is inevitable to create solutions to lower energy consumption. Also, modeling a standard building model according to the general characteristics of the residential building stock is necessary to be able to analyze the available energy efficiency improvements and renewable technologies accurately.

The aim of this study is to review the potential for energy improvement on the existing building stock of Turkey. In this context, the climatic regions across Turkey are identified and the average stock building characteristics are determined. Energy efficiency applications are investigated through the accessible and cost-effective technologies and know-how that have not as yet been widely adopted, which can improve energy efficiency in buildings and reduce greenhouse gas emissions to a significant extent. Technical and economic aspects of each energy efficiency measure are assessed to establish applicability of the measures in the study. Investment costs, savings and payback periods are all taken into consideration. The economic savings as well as energy and CO_2 savings of all the measures are evaluated via the assessment of the results. According to these findings, prioritization of the application of the energy efficiency measures can be suggested for the buildings with different characteristics in different climates. By this way, a more feasible approach can be suggested in terms of both technical and economical applicability and efficiency of the measures.

2. LITERATURE

Throughout 1980s and 1990s the increasing concerns about energy efficiency and greenhouse gas emissions have led to many academic researchers to cover these issues in their studies. These studies are usually focused on energy/industrial sector and buildings sector since they are the largest energy consuming platforms over the world. Especially in the recent decade, these kinds of researches have gained acceleration. Literature about the available measures about energy efficiency in buildings, energy efficient applications and methods and comparison of energy efficient measures for existing building stock in different climatic zones are reviewed in the scope of this thesis. Some selected relevant studies from literature are available in the following paragraphs.

Borg and Kelly (2011) investigated the effect of appliance energy efficiency improvements on domestic electric loads in European households (Borg and Kelly, 2011). They concluded that improving the energy efficiency of appliances in households leads to a significant reduction in electrical energy requirements (Borg and Kelly, 2011). In their study, it is concluded that switching to more energy-efficient appliances has a beneficial effect on the electrical energy consumption of domestic households, with annual average reductions in electrical consumption of 23% for the households investigated (Borg and Kelly, 2011).

Kalz et al. (2009) evaluated the energy efficiency performance of 12 buildings with different architecture and design in three different climate zones in Germany which were optimized with respect to primary energy use (Kalz et al., 2009). These buildings had different functions such as office building, residential building, school etc. In their study, buildings to be examined had a net floor area ranging between 300 and 21500 m^2 (Kalz et al., 2009). All of the buildings utilized environmental energy sources and energy sinks such as ground, ground water, rainwater and the ambient air (Kalz et al., 2009). Measures such as high quality building envelope, solar shading, sufficient thermal storage capacity, air ventilation system, low-energy office equipment were utilized to investigate energy performance of the buildings (Kalz et al., 2009). First of all, ventilation, heating and cooling systems of the buildings were examined, current primary energy use of these systems were defined then energy reduction potentials were specified according to the existing conditions (Kalz et al., 2009). They calculated the energy consumption of buildings if they met the target values stated in the “Energy Optimized Program” of Germany (Kalz et al., 2009).

They concluded that heating and cooling systems present huge potential for energy efficiency and saving (Kalz et al., 2009). They also concluded that; for the new non-residential buildings, the end energy use for heating, cooling, ventilation and lighting lies between 30 and 65 kWhend/(m^2 neta) which is one third lower than for the common German and Swiss building stock (Kalz et al., 2009). They found that most of the buildings studied met the target values of primary energy for the HVAC system and lighting by reducing the consumption by a factor of four compared to the common German and Swiss building stock (Kalz et al., 2009). Kalz et al. (2011) finally concluded that, low-energy cooling with sufficiently designed environmental heat sinks constitutes an energy efficient concept for both residential and non-residential buildings without disturbing thermal comport of the occupants (Kalz et al., 2009).

Hens (2010) investigated the energy efficient retrofit of an old residential building with long term measures have been carried on 1970s (Hens, 2010). He both measured and monitored the energy reduction and calculated the predicted results for space heating, domestic hot water, lighting and appliances (Hens, 2010). The house examined is built in 1950s and has two stories, a basement and a loft (Hens, 2010). Throughout last 30 years, some energy efficiency measures had been taken starting from insulation, double windows, efficient boiler and pumps, insulation of heating pipes, installing solar boiler and installing PV panels (Hens, 2010). He concluded that the benefits of the solar boiler and PV panels are less than insulation, energy efficient windows and central heating in terms of energy reduction (Hens, 2010). Another result of the study shows that insulation keeps its effect over the years and has a service life as the building (Hens, 2010). Solar boiler and PV panels are not to be found economically viable in the study (Hens, 2010).

Ouyang et al. (2011) states that refurbishment of existing buildings can offer an opportunity to take cost-effective measures in terms of resource efficiency and environment (Ouyang et al., 2011). Their study argues that refurbishment costs much less than demolition and reconstruction, therefore through the perspective of sustainability principles and policies, renovating old residential buildings together with energy efficient renovation makes more sense (Ouyang et al., 2011). Their study proposes that these activities provide various benefits, such as saving energy, decreasing environmentally pollution and promote inhabitants’ health (Ouyang et al., 2011). According to the findings of their study, technical energy saving measures can effectively reduce residential energy consumption comes from the three routes: (a) better insulation of building envelop (exterior wall, windows, roof and so forth), (b) enhancement of energy efficiency of appliances (household durables – for space heating, space cooling, amusement, cooking, and lighting) and (c) application of renewable energy to substitute for traditional energy, such as solar energy, underground heat resources, and biomass energy (Ouyang et al., 2011). In their study Ouyang et al. (2011) argue that all possible energy saving measures should be integrated into a suitable plan for the subject existing residential building (Ouyang et al., 2011). They also argue that, since not all possible energy saving measures are feasible and effective, and it is hard to evaluate the effects of every possible measures one by one, it is very necessary to apply site investigation, variable analysis and professional experience to pre-examine all potential measures to eliminate the unfeasible and/or useless ones, thereby to reduce mass workload in later process and make whole design process faster (Ouyang et al., 2011). According to their study, to judge the efficiency of one energy efficiency measure is very important to determine whether to implement or not (Ouyang et al., 2011). Therefore in their study, Ouyang et al. (2011) recommend three indexes which are energy-saving effect, CO_2 emission reduction effect and cost reduction effect as evaluation indexes (Ouyang et al., 2011). Ouyang et al. (2011) propose an appropriate methodology for building refurbishment based on (a) to select the feasible and effective energy-saving measures within their capability, (b) to evaluate the effects of energy-efficient renovation comprehensively and accurately, and (c) to advance a suitable energy-efficient renovation plan and to estimate its potential for the subject existing residential building (Ouyang et al., 2011). Therefore, in their study, a house from the city of Hangzhou from China was chosen as a representative from the building stock (Ouyang et al., 2011). Thermal parameters of buildings envelope and heating and cooling loads according to the climatic conditions were specified (Ouyang et al., 2011). Six improvement measures about were chosen to be implemented to the building envelope such as insulation, double windows applying curtains to exterior windows and so forth (Ouyang et al., 2011). Energy consumption for heating and cooling loads by energy efficient measures was calculated (Ouyang et al., 2011). Additionally, CO_2 emission reduction effects were calculated by simple $LCCO_2$ method (Ouyang et al., 2011). In the study, to calculate final energy improvements, improvement of occupant behavior was also considered by have an extra 10% decrease in heating and cooling loads (Ouyang et al., 2011). Finally, for next 20 years of the building examined, nearly 268.353 kWh energy was supposed to be saved, 202-211 tons of CO_2 reduction was supposed to be achieved and 35-49 thousands $ was supposed to be saved (Ouyang et al., 2011).

Tommerup and Svendsen (2006) review the technical energy saving possibilities that are available for existing residential units in Denmark and propose a financial methodology used for assessing energy saving measures (Tommerup and Svendsen, 2006). In their study, in order to estimate the total savings potential, detailed calculations have been performed in a case with two typical buildings representing the residential building stock and based on these calculations an assessment of the energy-saving potential is performed (Tommerup and Svendsen, 2006).

Improvement of roof insulation, energy saving glazing and insulation of external walls were chosen as energy efficiency measures to be examined (Tommerup and Svendsen, 2006). They concluded that 50% reduction of heat loss and 46% reduction of heating requirement are possible by implementing all the above-mentioned measures (Tommerup and Svendsen, 2006). In their study, payback period of the all measures were calculated as 30 years only by considering energy savings (Tommerup and Svendsen, 2006). They also concluded a profitable savings potential of energy used for space heating of about 80% is identified over 45 years within the residential building stock if the energy performances are upgraded when buildings are renovated (Tommerup and Svendsen, 2006).

In another study, a model which represents the building stock of the EU and that allows assessing the environmental impacts for all life cycle phases from construction to demolition was developed by Nemry et al. (2010) (Nemry et al., 2010). First of all, by utilizing statistical data of Eurostat, typology and characteristics of the building stock were identified according to their age, structure and built are in order to specify environmental reduction potential (Nemry et al., 2010). Building types (single-family houses, multi-family houses and high-rise buildings) that represent common buildings of EU-25 and three climatic regions of EU-25 according to heating degree days (Northern, Southern and Central Europe) were defined (Nemry et al., 2010). Afterwards, related energy and environmental improvement options were analyzed and lastly their cost efficiency was assessed (Nemry et al., 2010). Since energy demand for heating was found as most crucial element in the use phase of both existing and new buildings, three improvement options which help to reduce energy demand for heating such as additional roof insulation, additional façade insulation and new sealing to reduce ventilation were specified (Nemry et al., 2010). Refurbished representative buildings were compared to a base case which did not experience any improvement (Nemry et al., 2010). As a result, Nemry et. al. (2010) concluded that emissions were reduced by at least 20% compared to base case for a majority of building types and climatic zones (Nemry et al., 2010). They also reached that, heat losses through roof and external walls in single family houses are significant and therefore major economically efficient environmental improvement potentials exist for single-family houses (Nemry et al., 2010). All in all, it is concluded that different environmental impacts and improvement potential were obtained for different climatic zones and building types (Nemry et al., 2010).

Brecha et al. (2011) investigated the measures to reduce energy consumption and carbon reduction in specific existing residential buildings in one region (Brecha et al., 2011). They derived a standard home model which represents the general characteristics of homes in a state in the United States (Brecha et al., 2011). Firstly, physical characteristics, total energy consumption based on heating-degree-hours and electricity and natural gas consumption patterns of the houses in the region were identified, then several scenarios for energy efficiency improvements were examined (Brecha et al., 2011). Once the abovementioned characteristics were specified for the model house, scenarios were applied and economic estimates based on costs and benefits of the retrofits were carried out (Brecha et al., 2011). Four energy efficiency scenarios to be applied to existing homes were specified: (a) behavior scenario which addresses measures which can be easily undertaken by the residents, (b) sealing leaks scenario which considers sealing ducts and reducing the infiltration to the home, (c) sealing leaks + attic scenario which considers both sealing and maximizing attic insulation, (d) deep retrofit scenario which considers maximum reduction in leakage, maximum insulation of walls, floors, doors and attic, upgrading windows and heating and cooling equipment (Brecha et al., 2011). First scenario is the lower cost one, while the last one is the higher cost scenario (Brecha et al., 2011). According to their findings, all scenarios provide significant reductions in natural gas, electricity and greenhouse gas emissions (Brecha et al., 2011). The largest reduction levels are achieved in the fourth scenario (74% in natural gas consumption, 49% in electricity consumption and 59% in greenhouse gas reduction) whereas the smallest reduction levels are obtained in the first scenario (13% in natural gas consumption, 26% in electricity consumption and 21% in greenhouse gas reduction) (Brecha et al., 2011). Brecha et al. (2011) concluded that there is no “one size fits all” solution in energy and greenhouse gas reduction and to reach these reduction targets, region specific (climate specific) measures should be taken to be applied in existing residential stock (Brecha et al., 2011).

Another study done by Sadineni et al. (2011) identifies potential energy efficiency upgrades applicable to homes in Las Vegas in the Unites States (Sadineni et al., 2011). In this study, available upgrades identified are evaluated with a building simulation software (Sadineni et al., 2011). An existing two-story single family house with 163.3 m^2 floor area and three bedrooms is used as a model house for the software (Sadineni et al., 2011). Possible upgrades are divided into two: (a) basic upgrades and (b) advanced upgrades (Sadineni et al., 2011). Basic upgrades are one step further from the basic requirements stated in International Energy Conservation Code (IECC) 2006 (Sadineni et al., 2011). They are easily applicable and have lower costs (Sadineni et al., 2011). These upgrades cover improving R-values of walls, doors, U-values of windows, changing incandescent lighting bulbs with CFLs, insulation of wall cavities and roof, higher efficiency air conditioners with better seasonal energy efficiency ratio (SEER) (Sadineni et al., 2011). Advanced upgrades are high above the standards and have higher costs (Sadineni et al., 2011). These upgrades include higher R-value walls with insulation, window with better energy values, increasing insulation at floor, roof, walls, higher SEER ratings for air conditioners, double layer roof and heat recovery ventilator for mechanical ventilation (Sadineni et al., 2011). Additionally, roof integrated PV systems are installed for renewable energy (Sadineni et al., 2011). Annual energy savings of each energy efficiency upgrade is calculated (Sadineni et al., 2011). Benefit cost analysis is carried out by considering energy cost inflation rate and payback periods are calculated for each (Sadineni et al., 2011). Sadineni et al. (2011) conclude that for energy cost inflation rate of 1% or more, all the basic upgrades have payback periods less than 10 years therefore applying basic upgrades are recommended (Sadineni et al., 2011). Similarly, PV systems are recommended due to higher benefit to cost ratio (Sadineni et al., 2011). However, not all advanced upgrades are recommended by Sadineni et al. (2011) since except high efficient windows and heat recovery ventilators advanced upgrades have longer payback periods (Sadineni et al., 2011). Additionally, in the study, energy saving of the upgraded home is compared with a code standard home (Sadineni et al., 2011). It is concluded that, the annual energy demand of the upgraded home is reduced by 42.5% compared to code standard home (Sadineni et al., 2011).

Chedid and Chajar (2004) studied the energy consumption reduction levels due to GHG mitigation scenarios in the residential buildings stock of Lebanon (Chedid and Chajar, 2004). They made an estimation of the residential buildings according to climatic zones and status such as “to be demolished”, “can be rehabilitated”, etc (Chedid and Chajar, 2004). Then they specified the thermal characteristics of the envelope of the buildings and energy consuming equipment (Chedid and Chajar, 2004). Wall, roof and windows are considered for thermal characteristics while refrigerator, domestic hot water systems and lighting are considered for energy consuming equipment (Chedid and Chajar, 2004). Energy reductions are calculated separately for thermal envelope and equipment (Chedid and Chajar, 2004). For improving thermal envelope, buildings specifications of Lebanese Standards Organization are taken into consideration and according to the implementation level of these specifications 12%-17% energy reductions are calculated (Chedid and Chajar, 2004). To reduce energy consumption, solar domestic hot water, energy efficient refrigerators and compact fluorescent lamps are evaluated in the study since they are pointed out in the Technical Annex to Lebanon’s First National Communication (Chedid and Chajar, 2004). According to calculations in the study, in short term (2005-2015) 4-8% reduction in energy consumption is found to be achievable and in long term (2040) the reduction level can be increased to 21% (Chedid and Chajar, 2004).

Al-Ragom (2003) studied the energy savings resulted from retrofitting residential buildings with energy efficient measures (Al-Ragom, 2003). He chose a house from Kuwait as a sample house which reflects the general characteristics of houses in Kuwait like physical and structural properties, construction materials and thermal properties of the envelope (Al-Ragom, 2003). This house is a two-storey building with a living space area of 307 m^2 (Al-Ragom, 2003). He focused on wall and roof insulation and efficient glazing systems for energy efficient improvement (Al-Ragom, 2003). He developed several retrofitting cases to compare with each other (Al-Ragom, 2003). Some involves one improvement while others have two or three of them (Al-Ragom, 2003). Specified improvements are wall insulation (R-10, R-15), roof insulation (R-15, R-20), clear single glass, clear double glass, reflective double glass and decreased window area (Al-Ragom, 2003). Energy savings as a result of improvements are calculated and payback periods for each retrofitting case are calculated as well (Al-Ragom, 2003). As a result, 7% energy consumption reduction is achieved by adding thermal insulation on the roof. And by applying clear double glass and reflective double glass, 9.1% and 17.69% energy consumption reductions are obtained respectively (Al-Ragom, 2003). He also showed that decreasing window area contributed to energy consumption reduction by 10% (Al-Ragom, 2003). However, in the study, payback periods of the improvements are calculated to be very long (Al-Ragom, 2003).

Ballarini and Corrado (2009) analyzed the energy performance of some existing buildings in Turin in Italy (Ballarini and Corrado, 2009). They investigated the energy performance of six buildings in order to gather data on the energy behavior of the building stock in that region (Ballarini and Corrado, 2009). They utilized “standard energy rating” method specified in The European Energy Performance of Buildings Directive (Ballarini and Corrado, 2009). They investigated energy performance by both calculating and measuring past data of buildings. They gathered main features of buildings such as geometrical parameters, constructive properties, typological features and energy consuming system data (Ballarini and Corrado, 2009). Heating, cooling, ventilation, domestic hot water system and lighting are considered as energy consuming systems in buildings subjected to analysis (Ballarini and Corrado, 2009). Both measured and calculated results were analyzed and obtained high values of energy consumption (Ballarini and Corrado, 2009). As a result, Ballarini and Corrado (2009) tried to highlight the need for an urgent energy renovation of the existing buildings stock (Ballarini and Corrado, 2009). They concluded that, dimensional, typological and constructive properties of buildings should be dealt with together in energy consumption reduction in buildings as they influence the building energy needs together (Ballarini and Corrado, 2009).

Ren et al. (2011) investigated some energy efficiency improvements and their cost effectiveness in terms of energy consumption and carbon emissions in residential buildings in eight cities of Australia (Ren et al., 2011). Cities were chosen from eight different climate zones of

Australia (Ren et al., 2011). Building thermal envelope, space heating and cooling, hot water, lighting and household appliances were analyzed as energy efficient improvements (Ren et al., 2011). All of these improvements were utilized for houses from eight cities (Ren et al., 2011). They concluded that improvements for energy consumption reduction and emission reduction and their cost effectiveness vary from climate zone to climate zone (Ren et al., 2011). They showed that for buildings in cold climate zones improving thermal envelope and insulation are more beneficial and should be prioritized whereas for buildings in warm and mild climate zones high energy efficient air-conditioning and appliances, on-site solar hot water and photovoltaics should be prioritized (Ren et al., 2011).

Ferrante and Semprini (2011) examined an existing residential building in Bologna which shows a poor energy performance (Ferrante and Semprini, 2011). In order to implement, they analyzed some energy efficiency improvements such as thermal insulation, windows, creating buffer zone between outside and inside of the building, photovoltaic panels, solar panels for domestic hot water, replacement of boilers with efficient ones and ground source heat pump (Ferrante and Semprini, 2011). They also investigated the investment cost and payback periods of improvements investigated (Ferrante and Semprini, 2011). They concluded that wall insulation and window glazing improvements are the ones which requires low initial costs and provides high energy performance (Ferrante and Semprini, 2011). According to results; photovoltaic systems, solar panels and ground source heat pumps provide substantial amount of energy consumption reduction (Ferrante and Semprini, 2011). However, results show that photovoltaic systems provides gain in longer term such as about ten years, similarly, solar panels and heat pump pay their initial costs in sixteen years (Ferrante and Semprini, 2011).

Nikolaidis et al. (2009) investigated some energy efficiency measures in a characteristic Greek home and then estimated the economic viability of the measures (Nikolaidis et al., 2009). They studied energy efficiency measures that fall into five categories such as; insulation, upgrading the existing heating system, solar thermal systems, upgrading the lighting and appliances, upgrading the cooling system and to be applied to a typical home in Greek (Nikolaidis et al., 2009). Amount of energy savings were determined by estimating the energy consumption amounts and cost of energy for both existing reference home and proposed retrofitting option (Nikolaidis et al., 2009). Economic evaluation of energy efficient measures were estimated by net present value (NPV), the internal rate of return (IRR), the savings to investment ratio (SIR), and the depreciated payback period (DPP) (Nikolaidis et al., 2009). They concluded that, upgrading lighting system, insulation and installing automatic temperature system to the boiler are the most effective investments by using IRR, while insulation is the most effective investment by using NPV (Nikolaidis et al., 2009). Moreover, replacement of windows and door frames is the least effective investment in terms of both IRR and NPV methods (Nikolaidis et al., 2009).

Chidiac et al. (2011) investigated the effectiveness of individual and a group of energy efficiency measures on a representative office building (Chidiac et al., 2011). In their study, typical office buildings which represent Canadian office stock were chosen (Chidiac et al., 2011). Three buildings were developed according to the time they had been built in order to represent all office stock with different envelope properties and construction characteristics (Chidiac et al., 2011). Envelop and system properties and typology of the buildings were specified for all building types (Chidiac et al., 2011). Measures such as improvement of wall, roof and window thermal efficiencies, upgrading HVAC (heating, ventilating and air-conditioning) system, improvement of boiler, daylight retrofit and improving the lighting system were chosen for assessment (Chidiac et al., 2011). The effect of both individual measures and group of measures were calculated. The combined effect of the measures was calculated as well (Chidiac et al., 2011). All the calculations were carried out for three different cities of Canada representing different climatic regions (Chidiac et al., 2011). As a result, improvements of building envelope combines with HVAC upgrade and improvement of lighting system provides greater reduction in energy consumption (Chidiac et al., 2011). Chidiac et al. (2011) concluded that the combined effect of daylight retrofit and HVAC upgrade can achieve 3-18% reduction in electrical consumption for different climate zones (Chidiac et al., 2011). Additionally, another conclusion of the study is that improving lighting system itself can provide 15% reduction of electrical consumption for all climate zones (Chidiac et al., 2011).

A number of studies have been undertaken in Turkey related to energy efficiency development in buildings and commercial structures. Optimum building aspect ratios and south window sizes of residential buildings from thermal performance point of view were assess by Inanici and Demirbilek (2000) (Inanici and Demirbilek, 2000). Tiris et al. (1997) looked at modelling of SO2 pollution changes with improving thermal performance of buildings in Gebze, Turkey (Tiris et al., 1997). Seasonal energy requirements and fuel consumption for heating purposes were assessed for the city centers of Istanbul, Ankara, Bursa, Adana and Konya in Turkey by Durmayaz and Kadıoglu (2003) (Durmayaz and Kadıoglu, 2003). Bolatturk (2008) studied the optimum insulation thicknesses for external walls of buildings using cooling and heating degree-hours in the warmest regions of Turkey (Bolatturk, 2008). Bolatturk also (2006) determined optimum insulation thicknesses for building walls with respect to various fuels and climate zones in Turkey (Bolatturk, 2006). Calculations of optimum insulation thickness were carried out on a prototype building in

Bursa as a sample city by Kaynakli et al. (2007) (Kaynakli et al., 2007). Aktacir et al. (2010) investigated the influence of building thermal insulation on cooling load and air-conditioning system in the hot and humid regions (Aktacir et al., 2010). Moreover, the performance assessment of a geothermally heated building in Izmir was carried out by Kalinci et al. (2009) (Kalinci et al., 2008). Ozgener (2010) investigated the use of solar assisted geothermal heat pump and small wind turbine systems for heating agricultural and residential buildings (Ozgener, 2010).

Eskin and Turkmen (2008) investigated the interactions between different conditions, control strategies and heating/cooling loads in office buildings in four climatic zones of Turkey (Eskin and Turkmen, 2008). Four cities were chosen as representatives and the effect of climatic conditions, insulation, aspect ratio, color of external surfaces, shading, window area, glazing system, ventilation rates on energy requirements of the buildings for each city were evaluated (Eskin and Turkmen, 2008). First of all, Istanbul, Ankara, Izmir and Antalya were selected as representative cities from climatic zones (Eskin and Turkmen, 2008). Building energy simulation was carried out by EnergyPlus and heating/cooling loads and annual energy requirement were calculated for each building (Eskin and Turkmen, 2008). At the same time, weather data of each city were gathered (Eskin and Turkmen, 2008). A real office building in Istanbul was chosen as a base case building in order to compare the simulation results and similar measures and calculations were carried out for this building as well (Eskin and Turkmen, 2008). As a result Eskin and Turkmen (2008) concluded that 75 mm thick insulation on the inside of the wall produces the maximum saving of 19.67% annual required cooling energy and 34.4% annual required heating energy in Istanbul, 21.06% annual required cooling energy and 26.82% annual required heating energy in Izmir, 21.35% annual required cooling energy and 27.19% annual required heating energy in Antalya, 19.86% annual required cooling energy and 35.93% annual required heating energy in Ankara when compared to the base case (Eskin and Turkmen, 2008). They also concluded that the effect of window ratio on building energy requirement is most significant at large aspect ratio for all cities (Eskin and Turkmen, 2008). Another result is that the maximum energy requirement of the low emissivity, double-glazing with clear glass double-glazing could be decreased for all cities for about 14%-16% (Eskin and Turkmen, 2008). Moreover, choosing light colors on external walls can provide 10% saving in annual energy requirements in hot climates and 3% in colder climates (Eskin and Turkmen, 2008).

Kikuchi et al. (2009) evaluated the energy efficiency measures for GHG reductions for residential buildings in five Canadian cities (Ottowa, Toronto, Montreal, Calgary and Vancouver) from different regions that are in different climate zones and vary in fossil fuel based electricity supply with different percentages (Kikuchi et al., 2009). A detached two-storey house in Canada as a reference building is specified (Kikuchi et al., 2009). Chosen energy efficiency measures were ground source heat pumps, photovoltaics, energy efficient appliances and lighting (Kikuchi et al., 2009). These measures were investigated individually and their combinations were investigated in order to identify in which regions they are more efficient (Kikuchi et al., 2009). Firstly, natural gas and electricity use of the standard house which has a conventional energy system is estimated as a base case and GHG emissions associated with this energy use by multiplying an emission factor (Kikuchi et al., 2009). Calgary has the largest emission factor for electricity since its electricity is provided by coal and gas while Montreal and Vancouver have the smallest emission factor for electricity since their electricity is provided by hydro power (Kikuchi et al., 2009). Toronto and Ottowa have a mixture of nuclear, coal, hydro and gas for electricity generation (Kikuchi et al., 2009). However, GHG emission factor for natural gas is the same for each city (Kikuchi et al., 2009). Secondly, in order to see the effectiveness of each technology, energy use of the house is calculated for each three cases (case GSHP-ground source heat pump, case PV-photovoltaics, case EEA-energy efficient appliances) (Kikuchi et al., 2009). Thirdly, two cases are developed as case GSHP + PV to compensate the electricity consumption of pumps in GSHP system and case PV + EEA to meet a larger portion of electricity demand (Kikuchi et al., 2009). Energy use of the standard house is calculated for combination of these technologies in order to understand if they are more effective in reducing GHG emissions (Kikuchi et al., 2009). By this way, electricity and natural gas consumption and GHG emissions are estimated for base case and five alternative scenarios (Kikuchi et al., 2009). Kikuchi et al. (2009) concluded that energy use varies with climatic conditions while total GHG emissions also depend on the source of electricity generation (Kikuchi et al., 2009). Cases including PV and EEA which are generating/saving electricity are more effective for Calgary which is most fossil-fuel dependent among other cities (Kikuchi et al., 2009). Cases including GSHP which provides reduction in natural gas consumption rather than reduction in electricity use is more effective in Montreal and Vancouver because emission factor for electricity is smallest in these cities since they utilize hydro power for electricity generation (Kikuchi et al., 2009).

In his PhD thesis, Çamlıbel (2011) developed a decision-making algorithm to improve energy efficiency of existing buildings which eliminates the uncertainty of financial and environmental benefits in order to spend funds most feasibly (Çamlıbel, 2011). He carried out a case study in which forty-two energy efficiency measures (such as insulation, improvement of lighting system and heating system, creating sunrooms to improve energy efficiency by passive design and so forth) are identified in terms of their potential savings and investment costs for seven existing buildings of a university campus (Çamlıbel, 2011). He analyzed existing buildings, measured their energy consumption, energy cost and carbon emissions and offered over four trillion possible combination of energy retrofit options (Çamlıbel, 2011). In order to prioritize options and hence use funds most feasibly, he came up with an optimization model which is used to maximize savings and not to exceed the budget for different budget scenarios ranging from $1000 to $600000 (Çamlıbel, 2011). In his study, he showed that the amount of return from the first $100000 is higher than the ones from the second and the third $100000 investments and there is a deviation range in investments done in existing buildings on which returns of investments decrease considerably and investing in another building become more effective from this point on (Çamlıbel, 2011). He showed that retrofitting of existing buildings with an optimized investment budget provides 33% saving in energy use, 22% saving in energy cost and 23% reduction in carbon emission (Çamlıbel, 2011). He also concluded that improving existing buildings is more efficient in terms of energy savings, carbon emissions and investment costs than both demolishing and constructing new buildings and producing new power plants (Çamlıbel, 2011).

In order to select an optimized set of energy efficiency measures, Tan et al. (2016) developed a decision model via mixed integer programming which maximizes financial and environmental returns of energy efficiency measures for existing buildings within budgetary constraints in single- and multi- period settings (Tan et al., 2016). In single- period setting, they came up with a decision model similar to the one presented in Çamlıbel's PhD thesis (2011) (Tan et al., 2016). However, in multi- period setting, they included the timing of investment by considering the future savings obtained from the energy efficient measures hence they use them as a fund to implement other energy efficient measures in the future (Tan et al., 2016). They concluded that multi- period setting results in higher financial and environmental savings for the same budget than that of single- period setting (Tan et al., 2016).

Valdiserri and Biserni (2016) compared three energy retrofitting solutions for an existing office building in northern Italy (Valdiserri and Biserni, 2016). The first retrofitting solution was to reduce the heat transfer by transmission, the second one was to decrease the ventilation losses and the third one was to apply the first and the second solutions together (Valdiserri and Biserni, 2016). In their study, they firstly developed a model of the existing building and investigated its energy performance (case 0) then they simulated three retrofitting solutions and estimated their energy performance (case 1, 2, 3) as well (Valdiserri and Biserni, 2016). After that, they calculated building's energy demand for different cases and developed four scenarios which show the energy saving level of each case over the existing case (case 0) (Valdiserri and Biserni, 2016). They compared the cases by carrying out technical and economic assessment and concluded that third case which offers applying two actions simultaneously results in better results (Valdiserri and Biserni, 2016).

Jafari and Valentin (2017) developed a decision-making framework which (a) states economic savings of energy efficiency measures for a specific existing building through its life-cycle, (b) defines optimum budget for energy retrofitting in order to minimize the life-cycle cost of that specified building and (c) selects the optimum combination of measures to maximize economic savings (Jafari and Valentin, 2017). For this purpose, they worked on a case study of a house built in 1960's in Mexico (Jafari and Valentin, 2017). They concluded/showed that (a) a minimum amount of life-cycle cost obtained at a budget of $11000, (b) maximum economic savings obtained by retrofitting measures such as installing thermostat and a solar thermal system, replacing lighting fixtures and dishwasher with energy efficient ones, replacing doors with insulated ones and insulating ceilings, walls and attic (Jafari and Valentin, 2017). They aimed to represent a model which can be adopted in other buildings in order to ease the decision making process which is a complex issue to be addressed in order to be able to realize investments of energy efficiency improvement of existing buildings (Jafari and Valentin, 2017).

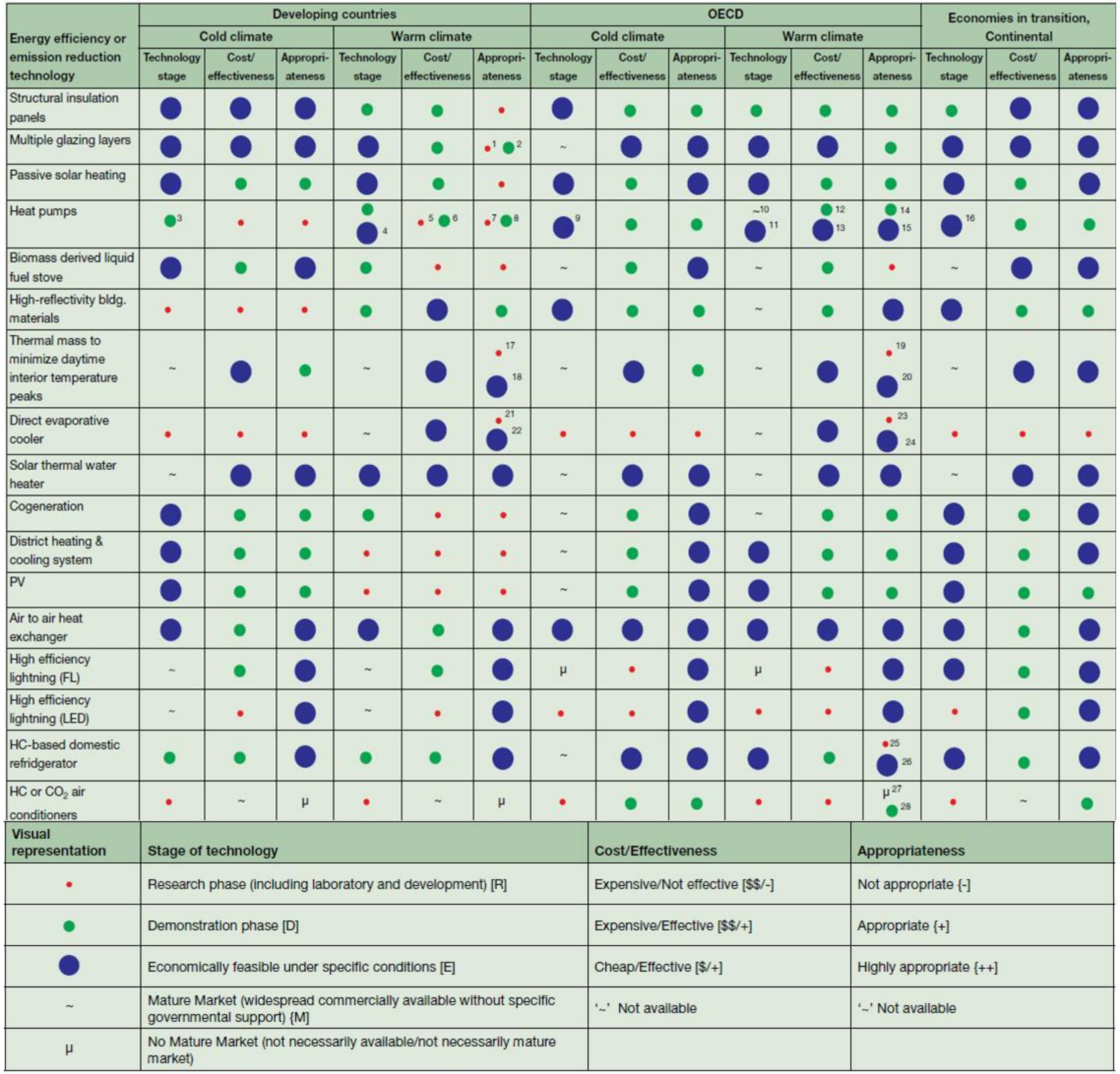
Some studies calculate environmental and financial benefits of energy efficiency measures and select the ones to be implemented through technical and economic assessment by using some methods like payback period (Tommerup and Svendsen, 2006; Sadineni et al., 2011; Al-Ragom, 2003; Ferrante and Semprini, 2011; Nikolaidis et al., 2009; Valdiserri and Biserni, 2016; Zhou et al., 2016; Huang et al., 2012; Mahlia et al., 2011), NPV (Nikolaidis et al., 2009; Valdiserri and Biserni, 2016; Mikulic et al., 2016; Penna et al., 2015; Wang and Holmberg, 2015), IRR (Nikolaidis et al., 2009; Doukas et al., 2009), life-cycle cost analysis (Mahlia et al., 2011; Wang and Holmberg, 2015; Ruparathna et al., 2017), benefit-cost analysis (Sadineni et al., 2011; Friedman et al., 2014; Wang et al., 2015) and levelized cost assessment method (Orioli and Di Ganghi, 2014; Akter et al., 2017; Khalid et al., 2017; Khalid et al., 2016; Streicher et al., 2017; Spoletini, 2017) whereas some does this by focusing on more complex decision-making models and propose selection processes based on optimization (Çamlıbel, 2011; Tan et al., 2016; Valdiserri and Biserni, 2016; Jafari and Valentin, 2017; Wu et al., 2015).

3. METHODOLOGY

The present study uses the following steps to achieve its goals: (a) selecting the potential energy efficiency measures that can be realistically undertaken in Turkey, (b) establishing the climatic characterization and the average building features within the climatic zone characterization, (c) performing an energy assessment of possible improvements with energy efficiency measures and estimation of building energy performance (d) assessing a technical and economic analysis.

The Fourth Assessment Report of Intergovernmental Panel on Climate Change (IPCC) provides a detailed review of available and implementable technology selection for various parts of the world which is summarized in Table 3.1 (Intergovernmental Panel on Climate Change, 2007). Since the economic and climatic conditions in regions largely determine the applicability and importance of technologies, countries are divided into three economic classes (developing countries, OECD, transition economies and continental countries) and two climatic types (cold and warm climates) according to the maturity of the technology, cost effectiveness and appropriateness. In Table 3.1 tilde mark indicates mature market while blue dots indicate economically feasible in terms of state of technology, cheap and effective in terms of cost/effectiveness and highly appropriate in terms of appropriateness. Green dots in the same table indicate demonstration phase in terms of state of technology, expensive and effective in terms of cost/effectiveness and appropriate in terms of appropriateness whereas red dots indicate research phase in terms of state of technology, expensive and not effective in terms of cost/effectiveness and not appropriate in terms of appropriateness. Similarly, the same study of Intergovernmental Panel on Climate Change shows the greenhouse gas mitigation measures and their relative potential for various parts of the world as shown in Table 3.2.

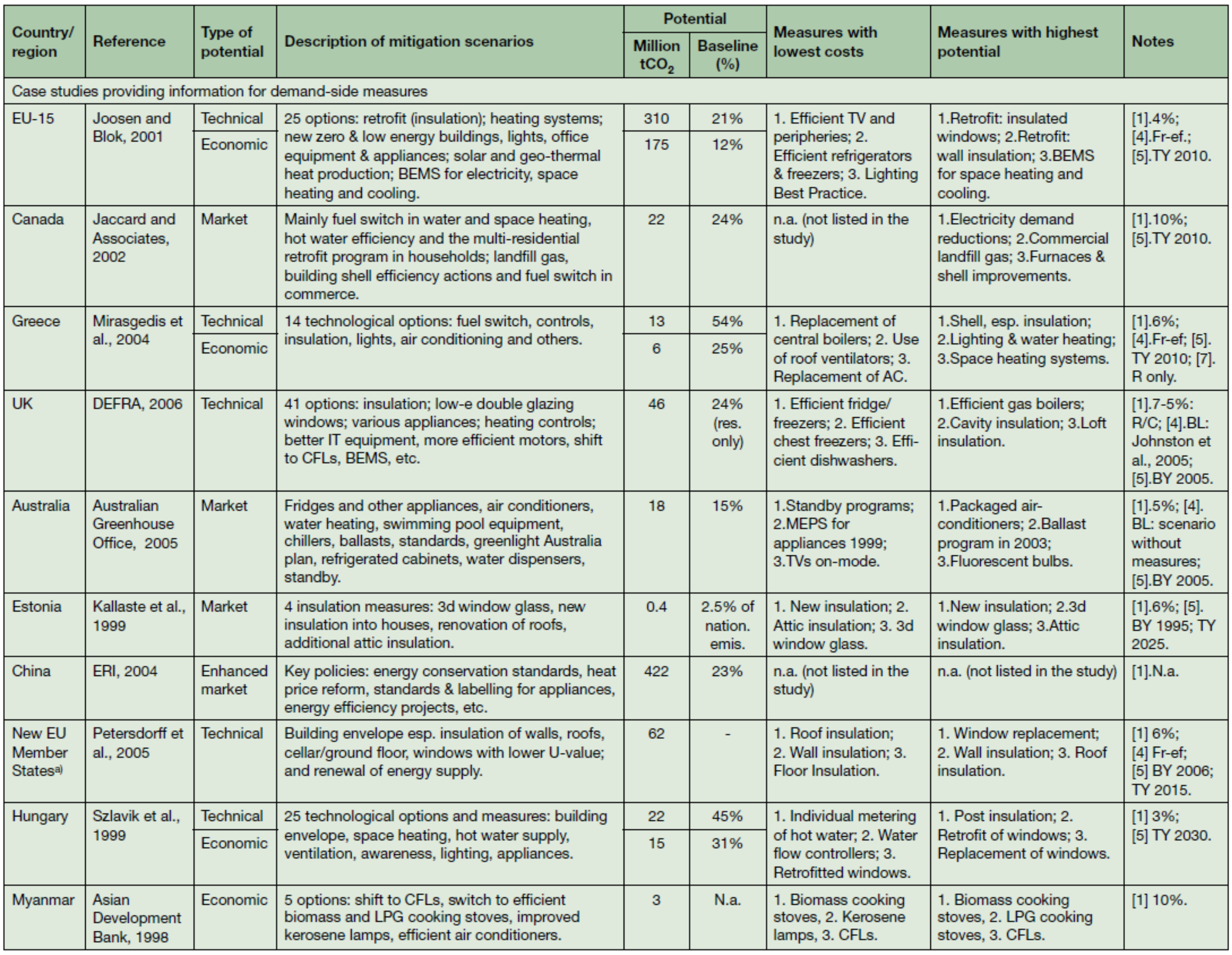
Table 3.1. Applicability of some energy efficiency measures in different regions (Intergovernmental Panel on Climate Change, 2007).



Energy efficiency or emission reduction technology	Developing countries						OECD						Economies in transition, Continental		
	Cold climate			Warm climate			Cold climate			Warm climate					
	Technology stage	Cost/ effectiveness	Appropri-ateness	Technology stage	Cost/ effectiveness	Appropri-ateness	Technology stage	Cost/ effectiveness	Appropri-ateness	Technology stage	Cost/ effectiveness	Appropri-ateness	Technology stage	Cost/ effectiveness	Appropri-ateness
Structural insulation panels	🔵	🔵	🔵	🟢	🟢	🔴	🔵	🟢	🟢	🟢	🟢	🟢	🟢	🔵	🔵
Multiple glazing layers	🔵	🔵	🔵	🔵	🟢	🔴[1] 🟢[2]	~	🔵	🔵	🔵	🔵	🟢	🔵	🔵	🔵
Passive solar heating	🔵	🟢	🟢	🔵	🟢	🔴	🔵	🟢	🔵	🔵	🟢	🟢	🔵	🟢	🔵
Heat pumps	🟢[3]	🔴	🔴	🟢 🔵[4]	🔴[5] 🟢[6]	🔴[7] 🟢[8]	🔵[9]	🟢	🟢	~[10] 🔵[11]	🟢[12] 🔵[13]	🟢[14] 🔵[15]	🔵[16]	🟢	🟢
Biomass derived liquid fuel stove	🔵	🟢	🔵	🟢	🔴	🔴	~	🟢	🔵	~	🟢	🔴	~	🔵	🔵
High-reflectivity bldg. materials	🔴	🔴	🔴	🟢	🔵	🟢	🔵	🟢	🟢	~	🟢	🔵	🔵	🟢	🟢
Thermal mass to minimize daytime interior temperature peaks	~	🔵	🟢	~	🔵	🔴[17] 🔵[18]	~	🔵	🟢	~	🔵	🔴[19] 🔵[20]	~	🔵	🔵
Direct evaporative cooler	🔴	🔴	🔴	~	🔵	🔴[21] 🔵[22]	🔴	🔴	🔴	~	🔵	🔴[23] 🔵[24]	🔴	🔴	🔴
Solar thermal water heater	~	🔵	🔵	🔵	🔵	🔵	~	🔵	🔵	~	🔵	🔵	~	🔵	🔵
Cogeneration	🔵	🟢	🟢	🟢	🔴	🔴	~	🟢	🔵	~	🟢	🟢	🔵	🟢	🔵
District heating & cooling system	🔵	🟢	🟢	🔴	🔴	🔴	~	🟢	🔵	🔵	🟢	🟢	🔵	🟢	🔵
PV	🔵	🟢	🟢	🔴	🔴	🔴	~	🟢	🔵	🔵	🟢	🟢	🔵	🟢	🟢
Air to air heat exchanger	🔵	🟢	🔵	🔵	🟢	🔵	🔵	🔵	🔵	🔵	🔵	🔵	🔵	🟢	🔵
High efficiency lightning (FL)	~	🟢	🔵	~	🟢	🔵	µ	🔴	🔵	µ	🔴	🔵	🔵	🟢	🔵
High efficiency lightning (LED)	~	🔴	🔵	~	🔴	🔵	🔴	🔴	🔵	🔴	🔴	🔵	🔴	🟢	🔵
HC-based domestic refridgerator	🟢	🟢	🔵	🟢	🟢	🔵	~	🔵	🔵	🔵	🟢	🔴[25] 🔵[26]	🔵	🟢	🔵
HC or CO_2 air conditioners	🔴	~	µ	🔴	~	µ	🔴	🟢	🟢	🔴	🔴	µ[27] 🟢[28]	🔴	~	🟢

Visual representation	Stage of technology	Cost/Effectiveness	Appropriateness
🔴	Research phase (including laboratory and development) [R]	Expensive/Not effective [$$/-]	Not appropriate {-]
🟢	Demonstration phase [D]	Expensive/Effective [$$/+]	Appropriate {+]
🔵	Economically feasible under specific conditions [E]	Cheap/Effective [$/+]	Highly appropriate {++]
~	Mature Market (widespread commercially available without specific governmental support) {M]	'~' Not available	'~' Not available
µ	No Mature Market (not necessarily available/not necessarily mature market)		

Table 3.2. CO_2 emissions reduction potential in residential and commercial sectors (Intergovernmental Panel on Climate Change, 2007).



Country/ region	Reference	Type of potential	Description of mitigation scenarios	Potential		Measures with lowest costs	Measures with highest potential	Notes
				Million tCO_2	Baseline (%)			
Case studies providing information for demand-side measures								
EU-15	Joosen and Blok, 2001	Technical	25 options: retrofit (insulation); heating systems; new zero & low energy buildings, lights, office equipment & appliances; solar and geo-thermal heat production; BEMS for electricity, space heating and cooling.	310	21%	1. Efficient TV and peripheries; 2. Efficient refrigerators & freezers; 3. Lighting Best Practice.	1.Retrofit: insulated windows; 2.Retrofit: wall insulation; 3.BEMS for space heating and cooling.	[1].4%; [4].Fr-ef.; [5].TY 2010.
		Economic		175	12%			
Canada	Jaccard and Associates, 2002	Market	Mainly fuel switch in water and space heating, hot water efficiency and the multi-residential retrofit program in households; landfill gas, building shell efficiency actions and fuel switch in commerce.	22	24%	n.a. (not listed in the study)	1.Electricity demand reductions; 2.Commercial landfill gas; 3.Furnaces & shell improvements.	[1].10%; [5].TY 2010.
Greece	Mirasgedis et al., 2004	Technical	14 technological options: fuel switch, controls, insulation, lights, air conditioning and others.	13	54%	1. Replacement of central boilers; 2. Use of roof ventilators; 3. Replacement of AC.	1.Shell, esp. insulation; 2.Lighting & water heating; 3.Space heating systems.	[1].6%; [4].Fr-ef; [5]. TY 2010; [7]. R only.
		Economic		6	25%			
UK	DEFRA, 2006	Technical	41 options: insulation; low-e double glazing windows; various appliances; heating controls; better IT equipment, more efficient motors, shift to CFLs, BEMS, etc.	46	24% (res. only)	1. Efficient fridge/ freezers; 2. Efficient chest freezers; 3. Efficient dishwashers.	1.Efficient gas boilers; 2.Cavity insulation; 3.Loft insulation.	[1].7-5%: R/C; [4].BL: Johnston et al., 2005; [5].BY 2005.
Australia	Australian Greenhouse Office, 2005	Market	Fridges and other appliances, air conditioners, water heating, swimming pool equipment, chillers, ballasts, standards, greenlight Australia plan, refrigerated cabinets, water dispensers, standby.	18	15%	1.Standby programs; 2.MEPS for appliances 1999; 3.TVs on-mode.	1.Packaged air-conditioners; 2.Ballast program in 2003; 3.Fluorescent bulbs.	[1].5%; [4]. BL: scenario without measures; [5].BY 2005.
Estonia	Kallaste et al., 1999	Market	4 insulation measures: 3d window glass, new insulation into houses, renovation of roofs, additional attic insulation.	0.4	2.5% of nation. emis.	1. New insulation; 2. Attic insulation; 3. 3d window glass.	1.New insulation; 2.3d window glass; 3.Attic insulation.	[1].6%; [5]. BY 1995; TY 2025.
China	ERI, 2004	Enhanced market	Key policies: energy conservation standards, heat price reform, standards & labelling for appliances, energy efficiency projects, etc.	422	23%	n.a. (not listed in the study)	n.a. (not listed in the study)	[1].N.a.
New EU Member States[a)]	Petersdorff et al., 2005	Technical	Building envelope esp. insulation of walls, roofs, cellar/ground floor, windows with lower U-value; and renewal of energy supply.	62	-	1. Roof insulation; 2. Wall insulation; 3. Floor Insulation.	1. Window replacement; 2. Wall insulation; 3. Roof insulation.	[1] 6%; [4] Fr-ef; [5] BY 2006; TY 2015.
Hungary	Szlavik et al., 1999	Technical	25 technological options and measures: building envelope, space heating, hot water supply, ventilation, awareness, lighting, appliances.	22	45%	1. Individual metering of hot water; 2. Water flow controllers; 3. Retrofitted windows.	1. Post insulation; 2. Retrofit of windows; 3. Replacement of windows.	[1] 3%; [5] TY 2030.
		Economic		15	31%			
Myanmar	Asian Development Bank, 1998	Economic	5 options: shift to CFLs, switch to efficient biomass and LPG cooking stoves, improved kerosene lamps, efficient air conditioners.	3	N.a.	1. Biomass cooking stoves, 2. Kerosene lamps, 3. CFLs.	1. Biomass cooking stoves, 2. LPG cooking stoves, 3. CFLs.	[1] 10%.

When IPCC's review is considered for Turkey, which is an OECD country and located in warm climate, it is observed that blue dots and green dots mainly indicate technologies such as insulation, heat pump, solar thermal, PV, heat exchanger and so forth. Likewise, for many countries, insulation, energy efficient lighting, appliances, water and space heating systems can be observed as measures with highest potential and lowest cost from the review on emission reduction potential of IPCC.

Largest energy consuming activities in residential buildings are space heating, water heating, appliances and lighting (Intergovernmental Panel on Climate Change, 2014; International Energy Agency, 2008b; Intergovernmental Panel on Climate Change, 2007). Energy efficiency measures can be grouped into measures to develop savings (i.e. passive systems, natural light usage, education and occupant/usage habits), measures to improve efficiency (i.e. efficient lighting, appliances, ventilation and improvement of efficiency in cooling and heating) and usage of renewable energy sources (i.e. photovoltaics, solar panels, heat pumps, wind). Jafari and Valentin

(2017) suggest that energy efficiency measures to be implemented in existing buildings can be grouped as follows (a) enveloping measures such as insulation of roof and walls, replacement of windows and joints with energy efficient ones, (b) load reduction measures such as upgrading existing mechanical system and replacement of appliances and lighting fixtures with energy efficient ones, (c) renewable energy technologies such as solar thermal, photovoltaic, geothermal power systems and so forth, (d) controlling measures such as providing controls and monitors for mechanical and electrical systems and installing automation systems as well, (e) human behavior in such as changing energy consumption patterns of occupants/users (Jafari and Valentin, 2017).

Moreover, De Boeck et al. (2015) make a review of literature on improving energy efficiency in residential buildings and they concluded that three application areas and some related measures are distinguished as being analyzed more often such as; (a) envelope (roof and wall insulation), (b) HVAC (solar systems and heat pump) and (c) appliances and lighting (De Boeck et al., 2015). Literature review in the present study shows similar results with the study of De Boeck et al. (2015). Building areas/systems which are analyzed in previous studies are mostly envelope, HVAC, appliances and lighting (Borg and Kelly, 2011; Kalz et al., 2009; Hens, 2010; Tommerup and Svendsen, 2006; Nemry et al., 2010; Sadineni et al., 2011; Ballarini and Corrado, 2009; Chidiac et al., 2011; Inanici and Demirbilek, 2000; Tiris et al., 1997; Durmayaz and Kadıoğlu, 2003; Bolatturk, 2008; Bolatturk, 2006; Kaynakli et al., 2007; Aktacir et al., 2010; Kalinci et al., 2009; Ozgener, 2010; Eskin and Turkmen, 2008; Çamlıbel, 2011) and energy efficiency measures which are investigated more specifically are wall and roof insulation, appliances, lighting, heat pump, solar thermal and PV (Ouyang et al., 2011; Chedid and Ghajar, 2004; Ren et al., 2011; Ferrante and Semprini, 2011; Nikolaidis et al., 2009; Kikuchi et al., 2009; Jafari and Valentin, 2017; De Boeck et al., 2015; Geyer et al., 2017; Wu et al., 2017; Karmellos et al., 2015).

Review of IPCC’s review on available and implementable technology selection (Intergovernmental Panel on Climate Change, 2007), Jafari and Valentin’s classification of energy efficiency measures (Jafari and Valentin, 2017), abovementioned energy efficiency measures that are focused in previous studies and Turkey’s legal and regulatory framework on energy efficiency, renewable energy, insulation, efficient appliances and efficient lighting (Enerji Verimliliği Kanunu, 2007; Enerji Kaynaklarının ve Enerjinin Kullanımında Verimliliğin Arttırılmasına Dair Yönetmelik, 2008; Türk Standartları Enstitüsü, 2008; Binalarda Isı Yalıtım Yönetmeliği, 2008; Binalarda Enerji Performansı Yönetmeliği, 2008; Enerji ile İlgili Ürünlerin Çevreye Duyarlı Tasarımına İlişkin Yönetmelik, 2010; Ürünlerin Enerji ve Diğer Kaynak Tüketimlerinin Etiketleme ve Standart Ürün Bilgileri Yoluyla Gösterilmesi Hakkında Yönetmelik, 2011; Türkiye Cumhuriyeti

Çevre ve Şehircilik Bakanlığı, 2012; Türkiye Cumhuriyeti Enerji ve Tabii Kaynaklar Bakanlığı, 2012; Türkiye Cumhuriyeti Kalkınma Bakanlığı, 2014; Türkiye Cumhuriyeti Çevre ve Şehircilik Bakanlığı, 2016) resulted in the selection of the following measures for improving energy efficiency of existing buildings in this study: (a) efficiency improvement consisting of thermal insulation, lighting fixtures, electrical household appliances and, (b) renewable energy source usage consisting of heat pump, solar panel and photovoltaics. In this study, occupant behavior and complicated mechanical and electrical systems and automation systems as well are not considered in the scope of energy efficiency measures since the former depends directly on human behavior and can not be easily quantifiable and the latter is not expected to be common in existing buildings in Turkey.

Additionally, the present study focuses on environmental (energy saving and CO_2 emission reduction) and economic benefits (energy cost saving) but not social benefits hence they are not analyzed. Since Jafari and Valentin (2017) state that most funding decisions in the construction industry are often made on the basis of initial cost instead of on the basis of life-cycle cost (LCC) (Jafari and Valentin, 2017) and when the poor condition of existing residential building stock of Turkey is considered, life-cycle cost is not analyzed. Hence items regarding life-cycle cost analysis of buildings such as service life of buildings, building resale value, maintenance costs, tax credits/taxation cost, disposal cost and so forth are not considered. Any change in energy unit prices is neglected as well. Moreover, interactions between energy efficiency measures are partly neglected. Since this study aims to assess energy efficiency measures and to estimate energy improvement potential of existing residential buildings in Turkey, energy efficiency measures are assessed both individually and interactively for possible cases. However, in order to be able to suggest prioritization of the application of energy efficiency measures for the buildings with different characteristics in different climates, total saving potentials of appropriate energy efficiency measures are estimated by assessing them individually and investigating their combinations.

3.1. Thermal Insulation Regulations

Physical properties of buildings such as thermal mass, chemical and physical properties of building materials, their shape and also local climate are the most influential parameters that directly affect the space heating load of buildings. Therefore, thermal insulation is applied for reducing heat loss in buildings through the envelope.

In Turkey, the thickness of thermal insulation material that should be applied to buildings is determined according to Turkish Standard 825 (TS 825) ‘‘Thermal insulation requirements in buildings”. TS 825 is an application of ‘‘ISO 9164-Thermal insulation calculation of space heating requirements for residential buildings” and it is basically similar to “EN 832-Thermal performance of buildings calculation of energy use for heating residential buildings” (Türk Standartları Enstitüsü, 2008). In TS 825, the thickness of thermal insulation material can be determined according to the annual requirement of heating energy of the building which based on heat losses calculation. Turkey is classified into four climatic zones considering only heating energy requirement, but not cooling energy requirement, by using degree-day concept in TS 825. The first zone has the warmest summer conditions, while the fourth zone has the coldest winter conditions with respect to the other regions. The heating degree-day regions are shown in Figure 3.1. The climatic zone characteristics of Turkey are stated in Table 3.3.

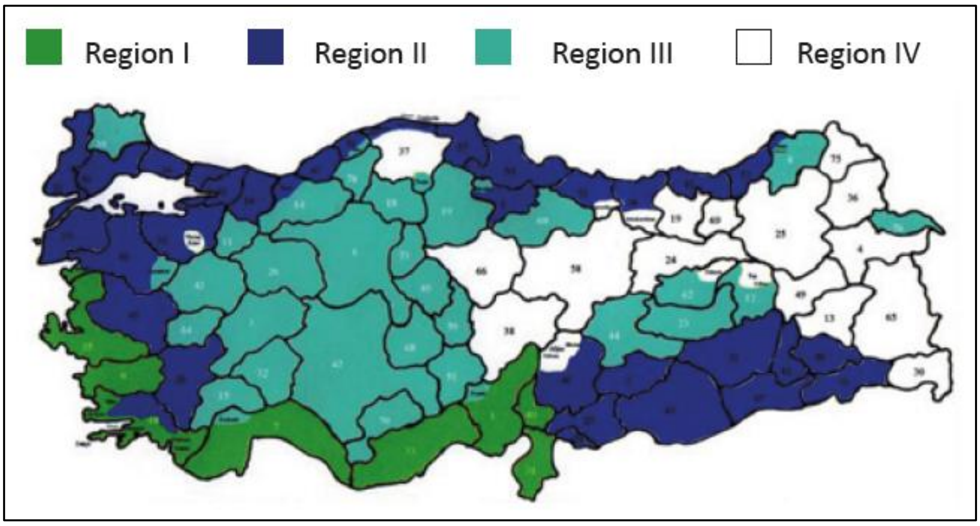


Figure 3.1. Heating degree-day regions of Turkey (Türk Standartları Enstitüsü, 2008; Yılmaz and Ganıç, 2015).

Table 3.3. The climatic zone characteristics.

zone	Heated Area		Outside Area		AtticArea		Non-Heated Area	
	Temperature ˚C	Relative Humidity %	Temperature ˚C	Relative Humidity %	Temperature ˚C	Relative Humidity %	Temperature ˚C	Relative Humidity %
1	20	60	5	90	10	80	13	75
2	20	50	0	80	5	70	8	65
3	20	40	-5	70	0	60	3	55
4	20	35	-10	60	-5	50	-2	45

The standard has shortcomings because cooling load of the building is not taken into consideration and the heat storage capacity of the building envelope is neglected. While heating is required in colder regions, cooling is needed in hotter regions of Turkey. Therefore, Turkey should be divided into some different cooling degree-day regions as well. Aktacir et al. (2010) state that the cooling degree days for the main provinces Sanliurfa (South-eastern Anatolia Region), Antalya (Mediterranean Region), Istanbul (Marmara Region) and Zonguldak (Black Sea Region) at 22˚C base temperature are 933 hours, 550 hours, 104 hours and 6 hours, respectively, although three of these cities are listed in the second region in TS 825 (Aktacir et al., 2010). Similarly, Yılmaz (2007) investigated the thermal performance of the same typical residential building in Istanbul and Mardin (Yılmaz, 2007). According to TS 825, both cities are considered in the second region. However they are in temperate-humid and hot-dry climatic zones, respectively. His study showed that cooling load in the same building in Mardin is larger than that of in Istanbul (Yılmaz, 2007).

It is stated in TS 825 that insulation should be applied according to PrEN ISO 13791 ‘‘Thermal performance of buildings – Internal temperatures of a room in summer without mechanical cooling – General criteria and calculation procedures” for cooling if necessary. However, this approach is not followed in Turkey even in the buildings for which cooling requirement is much more important than heating requirement (Aktacir et al., 2010). In some regions of Turkey, such as the South-eastern Anatolia, the Mediterranean and Aegean Regions, which have a hot climate and a longer cooling season than heating season, the thermal insulation applied considering only heating energy consumption using degree day concept is insufficient during hot seasons (Aktacir et al., 2006). Bolatturk (2008) studied the optimum insulation thicknesses for the building walls with respect to both cooling and heating degree-hours in the first climatic zone of Turkey (Bolatturk, 2008). He concluded that the application of insulation in building walls by using cooling degree hours is more significant for energy savings compared to heating degree hours in Turkey’s warmest climatic zone (Bolatturk, 2008).

Since in the last revised version of TS 825 which was released in 2008, only the heating requirement of the buildings is considered, thermal insulation is applied according to the heating loads. Therefore, despite the shortcomings of the TS 825, the present thesis takes the assessment of thermal insulation with respect to these existing conditions.

3.2. Standard Residential Building Setting

When the standard residential building is set, the degree day concept in TS 825 is utilized. All the provinces are grouped in TS 825 according to degree day regions. As it is stated before, there are four degree-day regions for the provinces of Turkey. The provinces and related degree day regions are as shown in Table 3.4.

Table 3.4. Provinces of Turkey and related degree day regions.

Degree Day Regions	**Provinces**
Region 1	Adana, Antalya, Aydin, Hatay, Mersin, Izmir, Osmaniye
Region 2	Sakarya, Adiyaman, Amasya, Balikesir, Bartin, Batman, Bursa, Canakkale, Denizli, Diyarbakir, Edirne, Gaziantep, Giresun, Istanbul, Kahramanmaras, Kilis, Kocaeli, Manisa, Mardin, Mugla, Ordu, Rize, Samsun, Siirt, Sinop, Sanliurfa, Sirnak, Tekirdag, Trabzon, Yalova, Zonguldak, Duzce
Region 3	Afyon, Aksaray, Ankara, Artvin, Bilecik, Bingol, Bolu, Burdur, Cankiri, Corum, Elazig, Eskisehir, Igdir, Isparta, Karabuk, Karaman, Kirikkale, Kirklareli, Kirşehir, Konya, Kutahya, Malatya, Nevsehir, Nigde, Tokat, Tunceli, Usak
Region 4	Agri, Ardahan, Bayburt, Bitlis, Erzincan, Erzurum, Gumushane, Hakkari, Kars, Kastamonu, Kayseri, Mus, Sivas, Van, Yozgat

In the present study, a typical standard residential building is specified by choosing a city from each region. When cities are selected from regions, population, urbanization and development levels are taken into consideration. At the end, Antalya from region 1, Istanbul from region 2, Ankara from region 3 and Erzurum from region 4 are selected as representative cities.

Following to the selection of cities, a common typology of the standard house in Turkey is specified. For this purpose, with the help of “Building Census 2000” (Türkiye İstatistik Kurumu, 2004) and “Turkey Residential Building Research” (Türkiye Cumhuriyeti Başbakanlık Toplu Konut İdaresi Başkanlığı and Türkiye Cumhuriyeti Devlet İstatistik Enstitüsü, 1999) reports, some findings are gathered and characteristics of the standard residential building for Turkey are specified. The findings are listed in Table 3.5. According to data from the abovementioned reports, the typical properties of the standard residential building are specified in the following paragraphs.

The standard residential building is specified with a total gross floor area of 220.72 m^2, building footprint area of 110.36 m^2 and gross floor area of 110.36 m^2 for each unit. The standard building has a ground floor and a first floor in other words two storeys. Each storey has one apartment. Each apartment serves four people. The building’s plan type is 2+1 with a sofa; that is, each apartment has two bedrooms and one guests’ room (living room) and also a sofa which is a hall-like room in typical Turkish houses. The plans, section and views are shown in Figure 3.2-3.9.

Table 3.5. Characteristic properties of the standard residential building in Turkey.

	Ankara	**Antalya**	**Erzurum**	**Istanbul**	**Average of cities**	**Average of Turkey**
Structure type	Masonry (72% masonry, 28% frame structure)	Masonry (61% masonry, 39% frame structure)	Masonry (63% masonry, 37% frame structure)	Frame Structure (27% masonry, 73% frame structure)	Frame Structure (46% masonry, 54% frame structure)	Masonry (55% masonry, 45% frame structure)
Wall material	Brick	Brick	Brick	Brick	Brick	Brick
Footprint area (m^2)	127.47	104.44	113.35	117.93	118.24	110.68
Average number of storeys (basement (if present) + ground floor + attic (if present))	1.99	1.70	1.70	3.04	2.50	1.96
Heating system	stove	stove	stove	stove	stove	stove
Physical condition	no need for repairs	no need for repairs	no need for repairs	no need for repairs	no need for repairs	no need for repairs
Waste water line connection	sewerage system	septic tank	sewerage system	sewerage system	sewerage system	sewerage system
Average number of rooms	-	-	-	-	-	3.5
Fuel type used in heating system	-	-	-	-	-	coal
Floor area per occupant (m^2)	-	-	-	-	-	25
Average size of house hold in Turkey	-	-	-	-	-	3.8

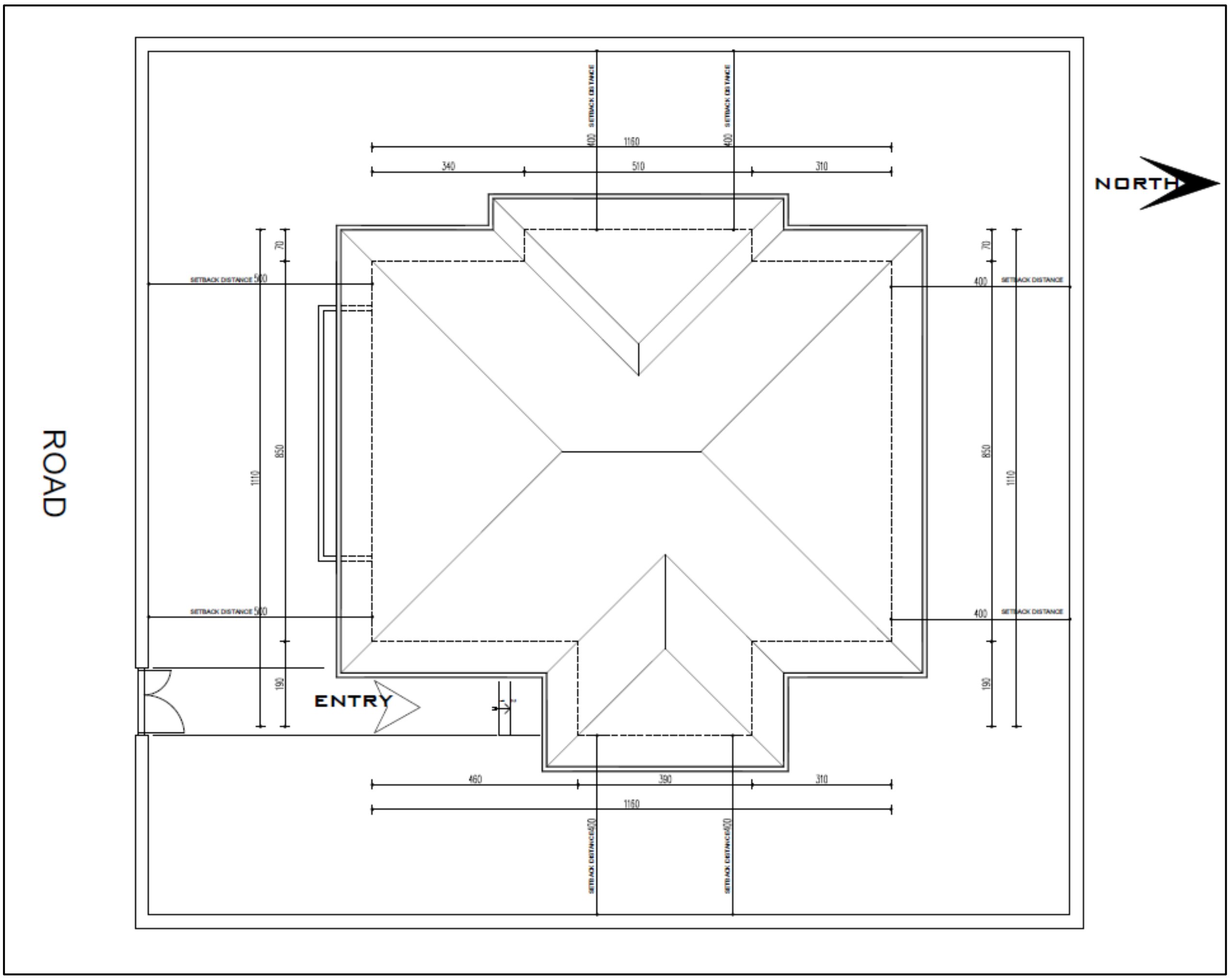


Figure 3.2. Layout plan.

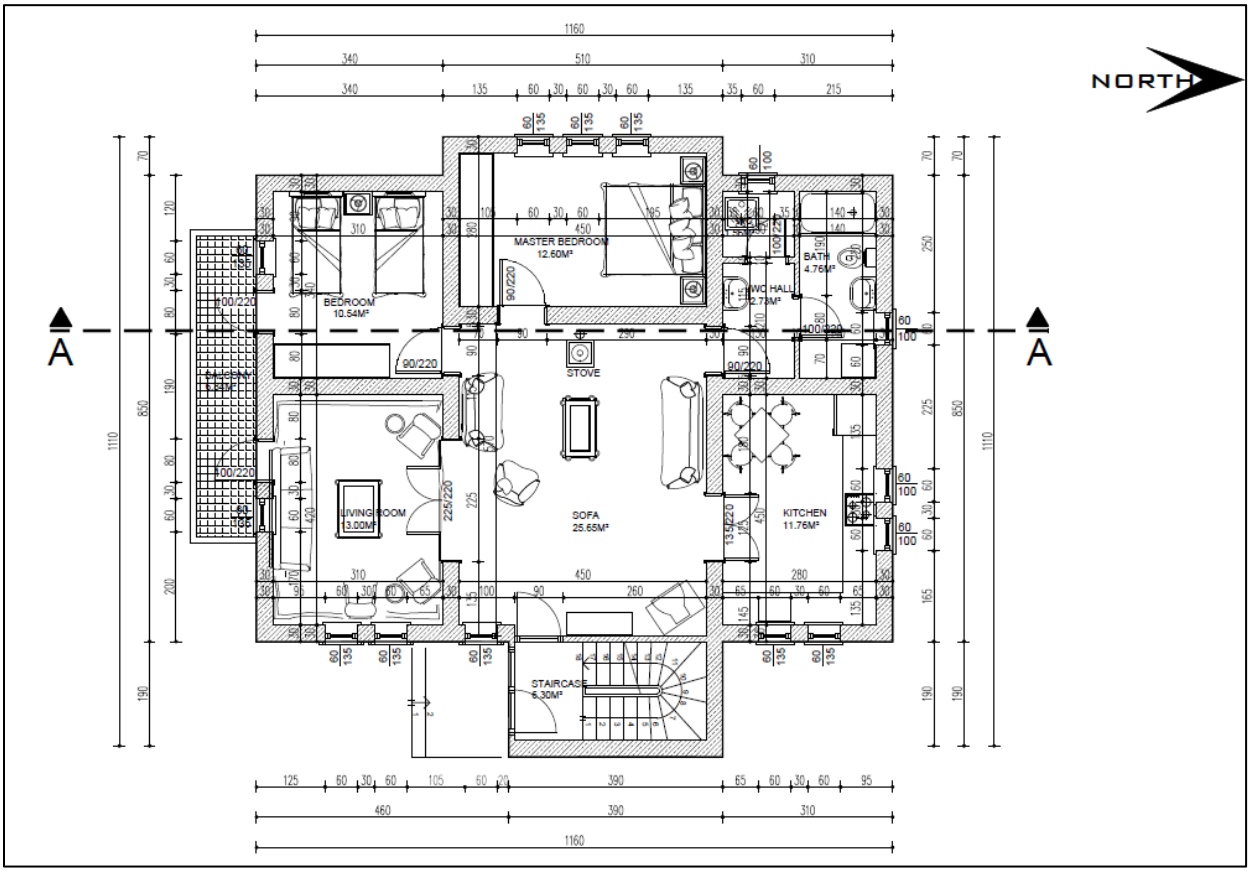


Figure 3.3. Ground floor plan.

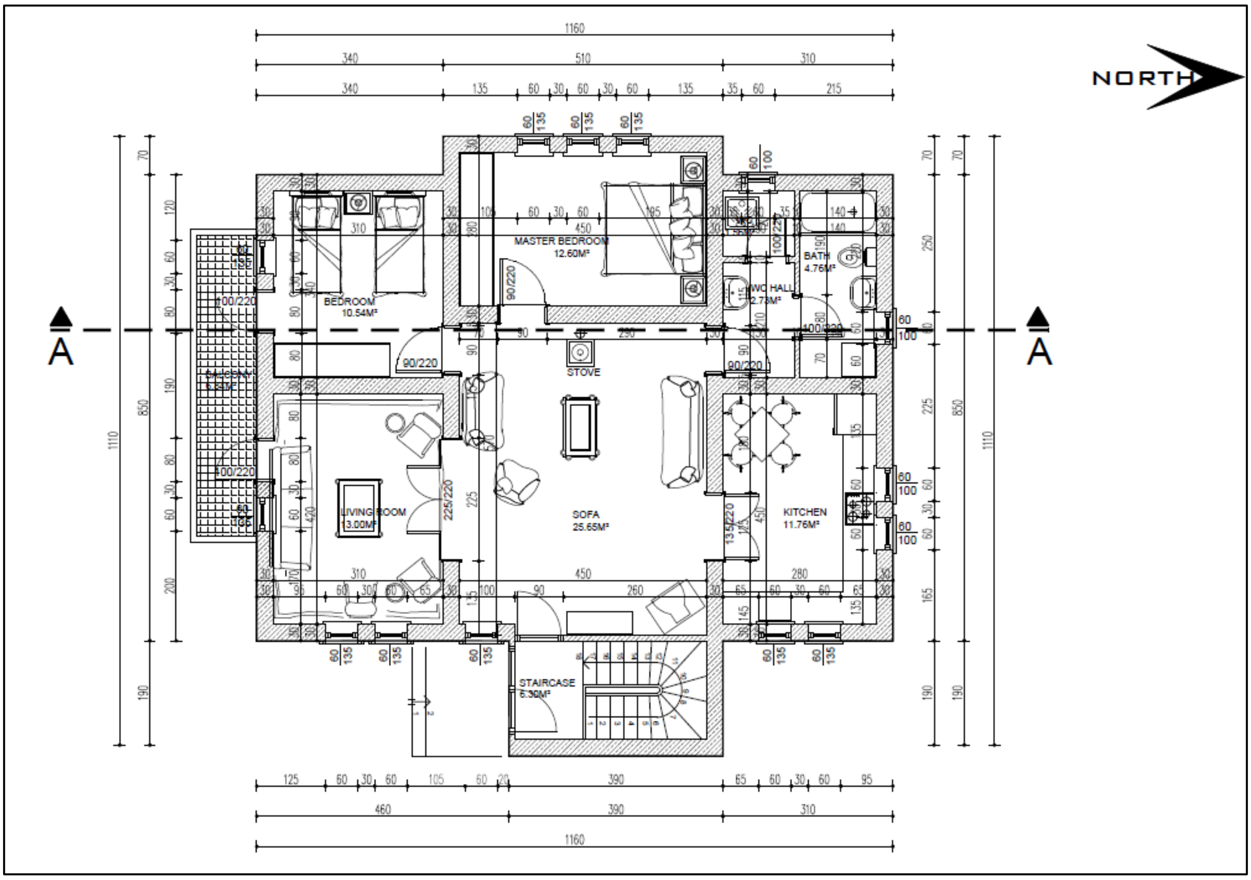


Figure 3.4. First floor plan.

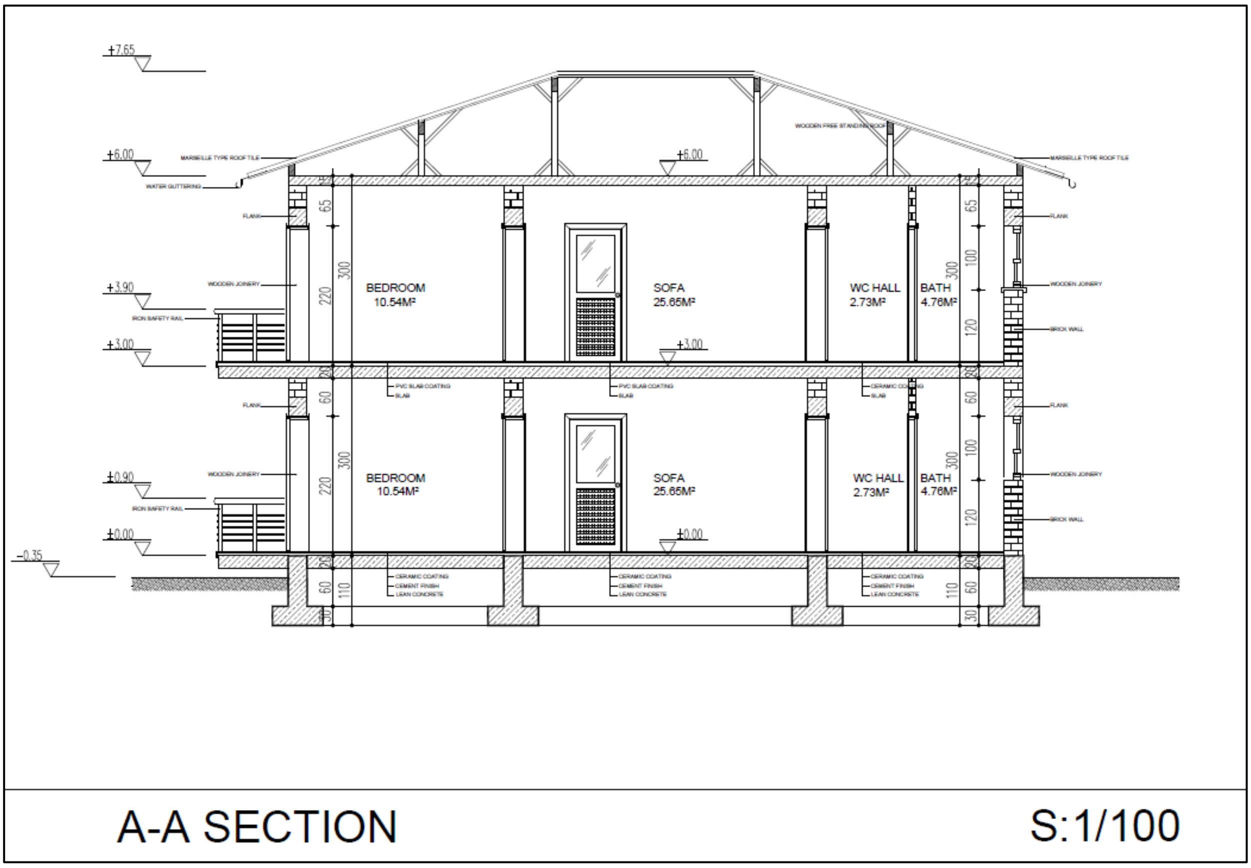


Figure 3.5. A-A section.

Figure 3.6. Front view.

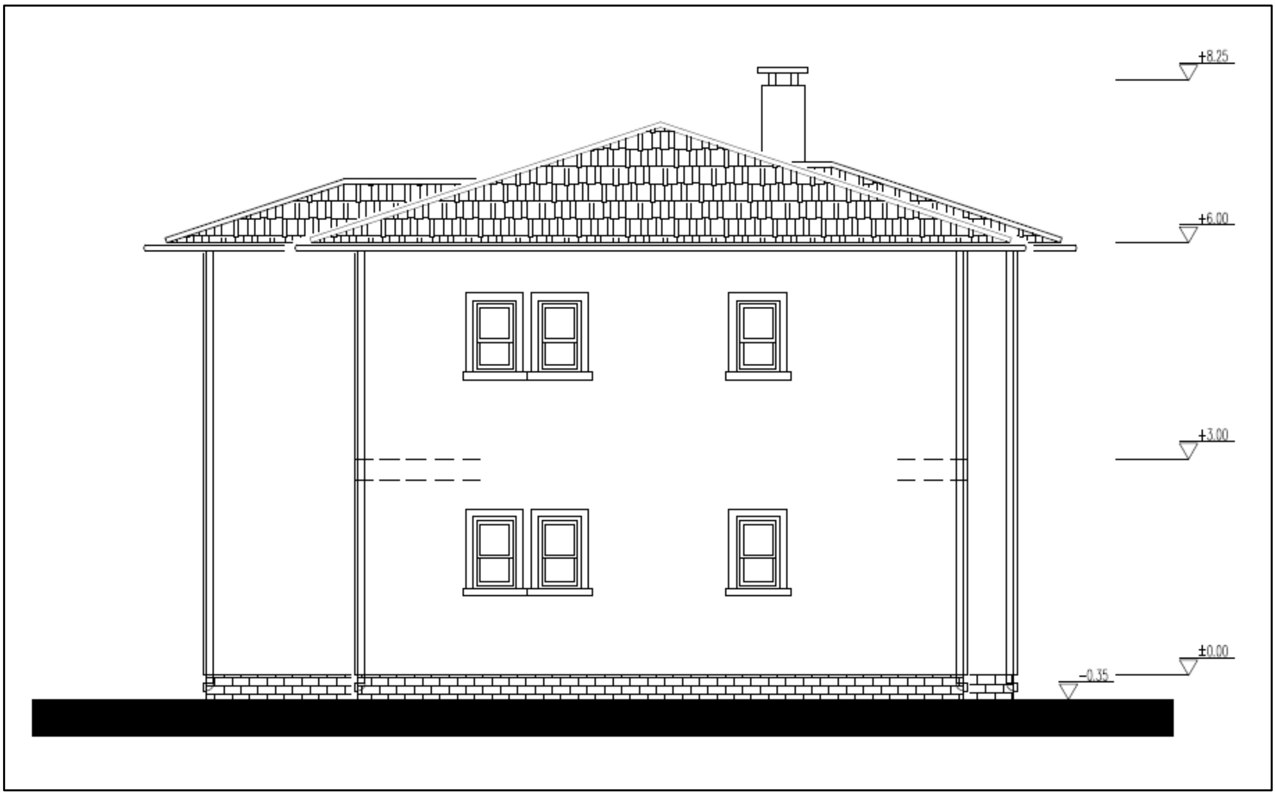


Figure 3.7. Rear view.

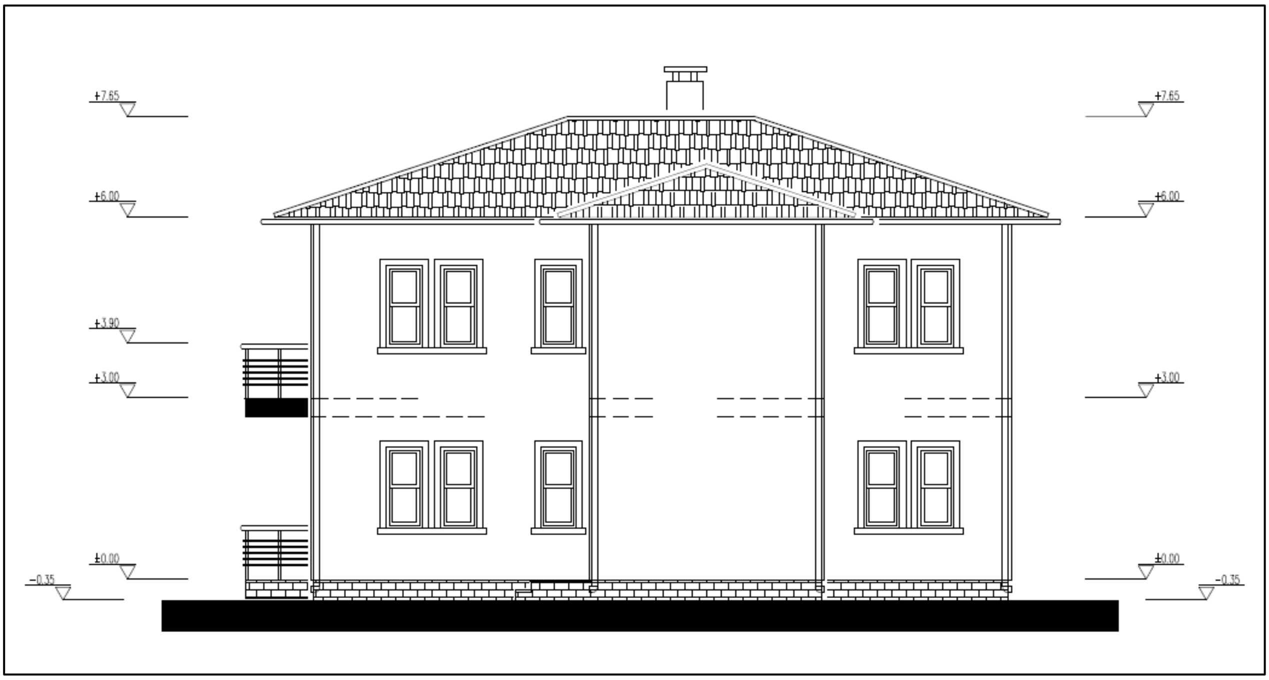


Figure 3.8. Side view I.

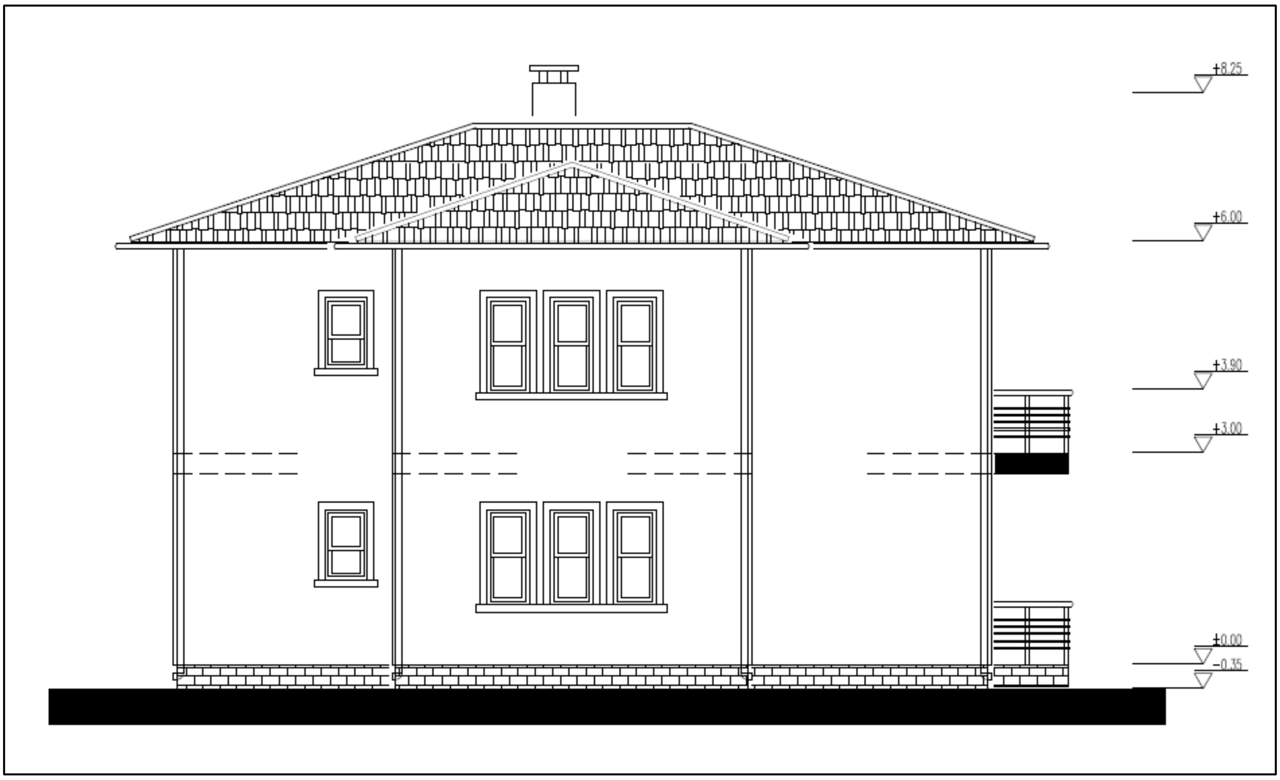


Figure 3.9. Side view II.

The internal usage of the standard residential building is specified as in Table 3.6.

Table 3.6. Internal usage of each apartment of the standard residential building.

building parts	**area (m^2)**
hall-like room (sofa)	25.65
guests' room	13.00
parents' bedroom	12.60
bedroom	10.54
kitchen	11.76
bathroom	4.76
WC	1.56
hall	2.73
balcony	6.84

The structural materials and the materials used in several elements of the standard residential building are listed as in Table 3.7.

Table 3.7. Materials of the standard residential building.

Building Elements	**Materials/Properties**
Structure	load bearing masonry (brick) wall
Joinery	wooden (main enrty door has aluminum joinery without insulation)
Floor covering	polyvinyl chloride (PVC) covering
Wet areas	ceramic covering
Exterior walls	cement plaster and paint
Roof	wooden frame and roof tile covering

3.3. Standard Appliances

Buildings contribute to 72% of the United States electricity consumption in 2006 and are predicted to contribute 78% of electricity consumption by 2030. Of this amount, 37% is consumed by the residential sector (U.S. Department of Energy, 2010). Most of the energy in residential sector is consumed by appliances with electronic devices and space heating. Figure 3.10 shows the primary energy end-use split in residential sector in the United States.

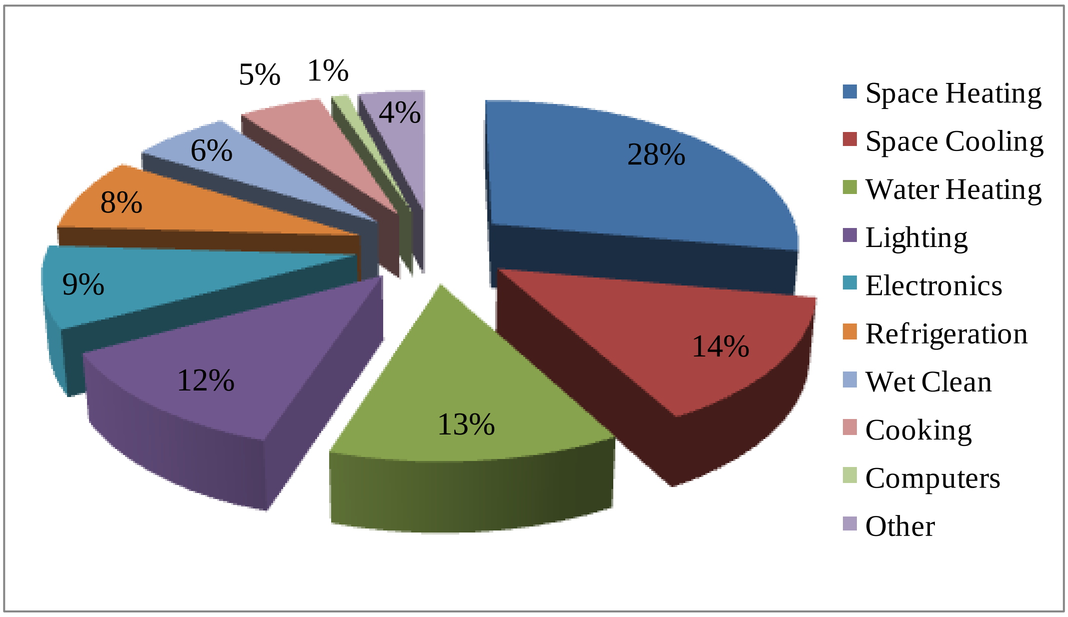


Figure 3.10. Primary energy end-use split in residential sector in the United States (U.S. Department of Energy, 2010).

In a typical U.S. home, appliances and home electronics are responsible for about 20% of energy bills. These appliances and electronics are mainly clothes washers and dryers, computers, dishwashers, home audio equipment, refrigerator and freezers, room air conditioners, televisions, DVD players and water heaters (U.S. Department of Energy, 2012).

For Turkey, the share of electrical energy consumption at residential buildings is given in Figure 3.11 based on the results of the Turkish Ministry of Industry and Trade (previous name of the Turkish Ministry of Science, Industry and Technology).

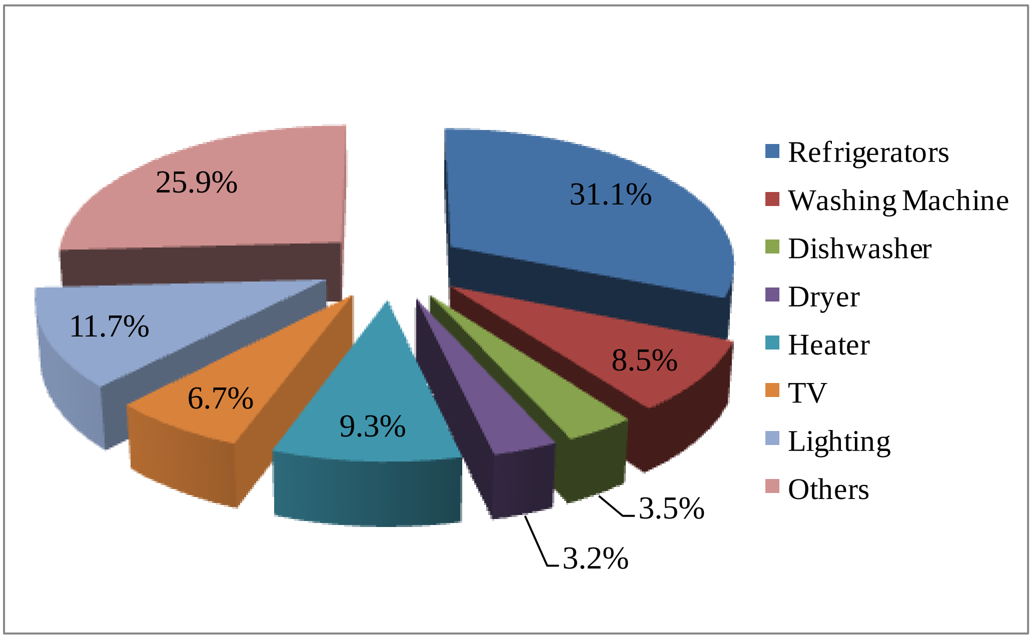


Figure 3.11. The share of electrical energy consumption of residential buildings in Turkey (Onaygil, 2010).

Mahlia et al. (2011) compared the existing and retrofitted lighting system of campus buildings of the University of Malaya in terms of potential energy saving, life cycle cost analysis and payback period and finally concluded that using energy efficient lighting system saves a significant amount of energy and cost and also reduces emissions (Mahlia et al., 2011).

As a result of abovementioned facts, it can be said that household and lighting appliances represent a great potential to reduce energy consumption in houses. Since preferring energy efficient appliances and compact fluorescent lamps (CFLs) to inefficient ones is an easily implementable improvement and directly effects energy consumption level, assessment of household appliances and lighting equipment are considered in this thesis.

The standard residential building in this study is assumed to have lighting and household appliances with the following specifications: (a) conventional incandescent light bulbs, 26 units (22 units x 66 watts, four units x 40 watts), (b) ralina lighting fixture, two units (two units x 32 watts), (c) low energy performance appliances (refrigerator, washing machine, cooker with oven, television, dishwasher), (d) electric thermosiphon for heating water, (e) natural gas fired stove for space heating, two units for each residential units (one in sofa, other in parents’ bedroom).

3.4. Potential Renewable Energy Sources for Standard Residential Building

3.4.1. Solar Panels and Photovoltaic Panels

Climatic conditions and variations in solar radiation play important role for the performance of the solar thermal and photovoltaic systems. For Turkey, available solar radiation is generally low in winter and autumn, while it is higher from April to November and it reaches its highest levels in July. Again, western and southern regions of Turkey are exposed to higher levels of solar radiation than of the rest regions. However, in Turkey the energy sources commonly used for hot water production are natural gas, electricity and fuel oil. Figure 3.12 shows the global irradiation and solar electricity potential of Turkey.

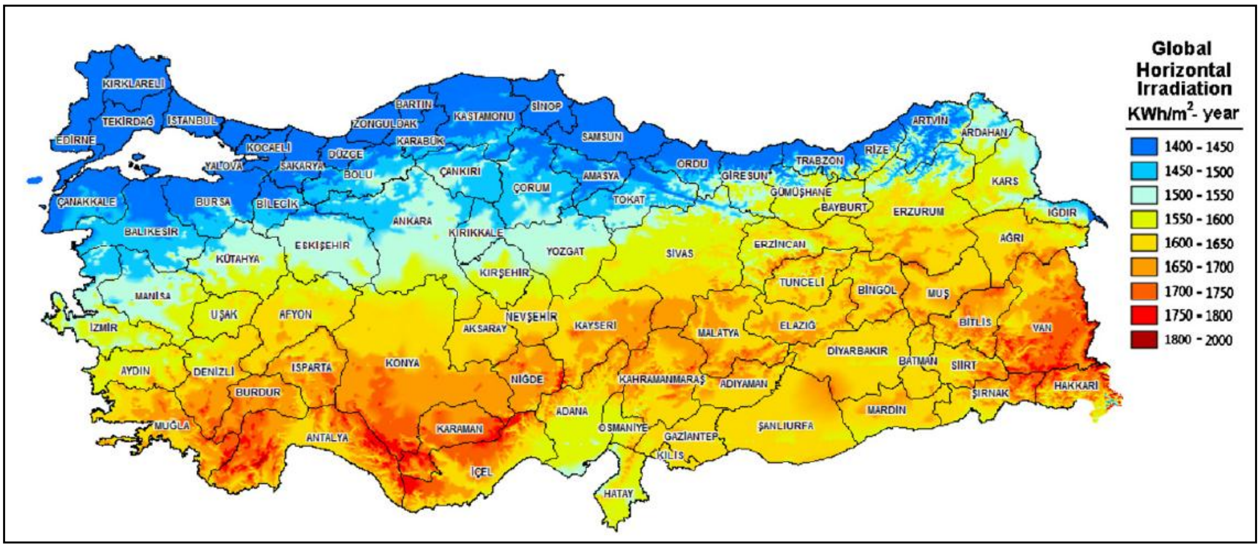


Figure 3.12. The global irradiation and solar electricity potential of Turkey (Türkiye Cumhuriyeti Enerji ve Tabii Kaynaklar Bakanlığı Yenilenebilir Enerji Genel Müdürlüğü, 2017b).

Solar energy is usually used in Turkey to heat water in Aegean and Mediterranean cities and to produce electricity for stand-alone buildings or areas where electricity transmission is not economically feasible. However, the electricity production from photovoltaic panels is still less than 1% of the national energy production in Turkey (Batman et al., 2012).

In the world solar panels are used in a variety of applications including solar hot water supplying, solar space heating and cooling and natural ventilation. In the 2008 Olympic projects of

Beijing, about 90% of domestic hot water is provided by solar collectors (Zhai et al., 2008). Solar collectors are considered to be a crucial contributor in the residential buildings for hot water supply. They are usually installed on the south tilted roofs, balconies and external walls in the buildings which are located in northern hemisphere.

Conventional solar water heating systems have three major parts which are a solar collector, water tanks and an auxiliary heating equipment. Gas or electricity can be used as auxiliary energy sources (Li and Yang, 2009). The parts are connected through copper pipes and valves to form a closed circulating system with a setting pressure (Zhai et al., 2008). The schematic diagram of a conventional solar hot water system is shown in Figure 3.13.

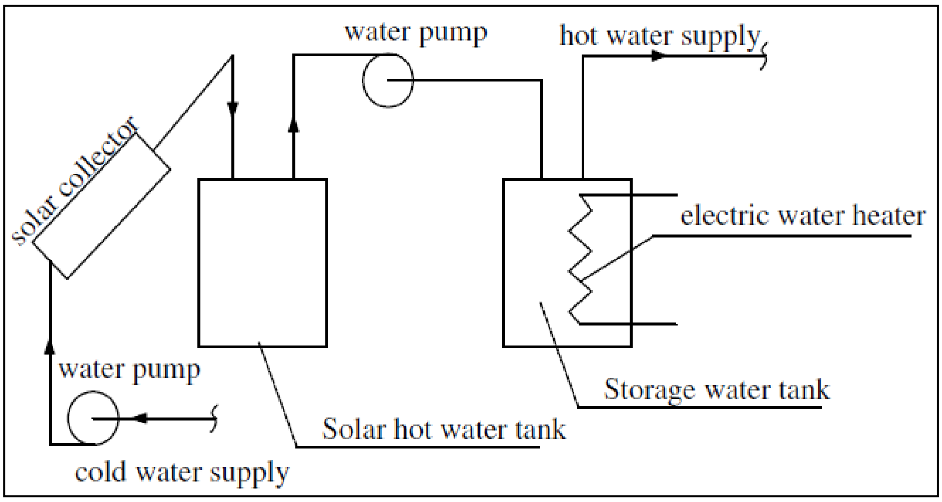


Figure 3.13. The schematic diagram of a conventional solar hot water system (Li and Yang, 2009).

Li and Yang (2009) analyzed different kinds of water heating systems for hot water production in Hong Kong and concluded that a solar thermal system has greater economic benefits than both an electric water heater and a towngas water heater with also a shorter payback period (Li and Yang, 2009).

Furundzic et al. (2012) showed that higher amounts of CO_2 emission reduction can be achievable even in case of conservation of the conventional fossil fuels by integration of solar water heating systems through the building refurbishment (Furundzic et al., 2012).

Ma and Wang (2009) stated that the results of the evaluations of the performance of the traditional water heating systems (i.e., electric water heaters and gas water heaters) and two kinds of solar thermal systems (i.e., conventional solar water heater systems and solar assisted heat pump systems) show that solar thermal systems have greater economic benefits than traditional water heating systems (Ma and Wang, 2009).

Likewise, Golic et al. (2011) stated that 20% of total energy consumption in building sector is used for water heating, and 8% of total energy in Europe is consumed for water heating purposes (Golic et al., 2011). Golic et al. (2011) also concluded that solar water heating systems are a suitable technology for renewable energy resource exploitation to be applied in residential building refurbishment which generate both fossil fuel saving and CO_2 emission reductions (Golic et al., 2011).

Photovoltaic systems can be grid-connected or off-grid systems. Unlike off-grid ones, grid-connected photovoltaic systems operate in parallel with the electric utility grid and as a result they usually require no storage systems. Since these systems supply additional power back to the grid when producing excess electricity which is greater than the demand, they help offset greenhouse gas emissions by displacing the power needed by the connected load and providing additional electricity to the grid (Obi and Bass, 2016).

A grid-connected PV system is usually comprised of a grid network, a PV array, an inverter and sometimes an optional battery storage. The PV array is the load power source and direct current (DC) output from the PV array is inverted into alternating current (AC) output in order to supply power to the loads of a building. Excessive DC power from the PV array can also be fed to the grid or stored in DC battery storage if there is. Power from the optional battery storage usually is not fed to the grid. If the PV array and the optional battery storage fail to produce enough power to meet the load demand of the building, the grid supplies power to the system. According to Lau et. al. (2016) in cases where excess electricity is generated by the PV array three cases are possible, (a) the excess electricity is unused (for grid-connected PV systems without battery storage), (b) the excess electricity is used to charge optional batteries (for grid-connected PV systems with battery storage), and (c) the excess electricity is fed to the grid (for grid-connected PV systems using the feed-in tariff scheme) (Lau et al., 2016). At night time where no solar output is available, the supply of electricity is provided by the grid or the optional battery storage if there is (Lau et al., 2016). The schematic diagram of a grid connected photovoltaic system is shown in Figure 3.14.

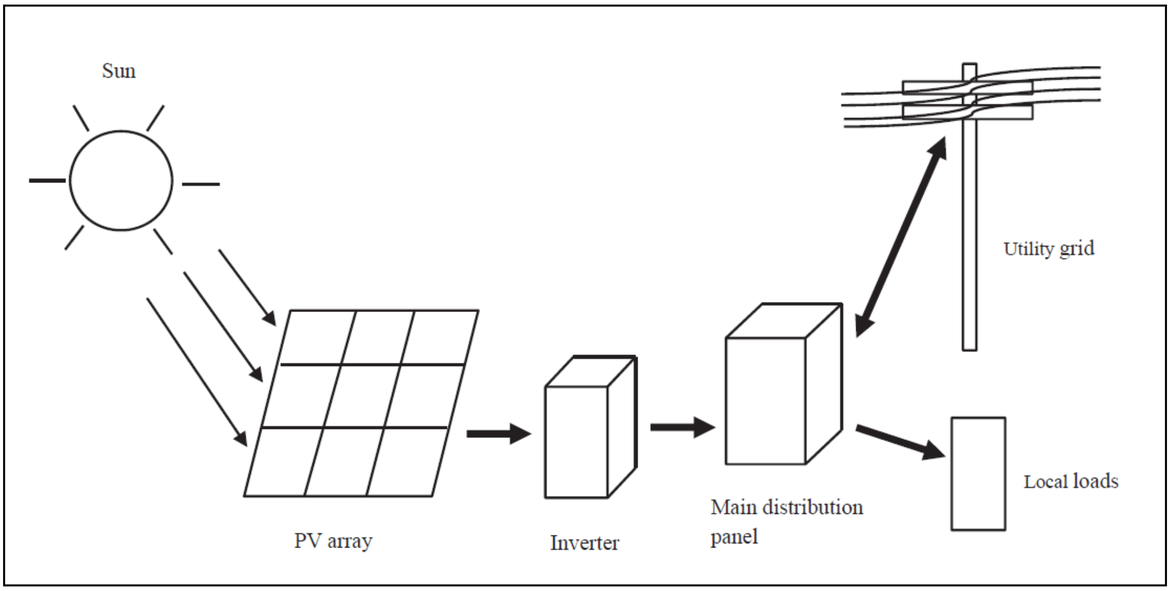


Figure 3.14. The schematic diagram of a PV system (Lau et al., 2016).

Koo et al. (2016) states some impact factors that should be considered in estimating the amount of electricity generation from PV systems (Koo et al., 2016). These factors are grouped into two, (a) regional characteristics such as latitude, meridian altitude, solar radiation and (b) building characteristics such as the azimuth angle of the panel, the slope of the panel and rooftop area (Koo et al., 2016).

Dabaieh et al. (2016) presented an approach to retrofitting local buildings in Egypt using photovoltaic solutions (Dabaieh et al., 2016). In their study, solutions for low-impact and self-sufficient retrofitting for local buildings are suggested, the rooftop PV system’s influence on overall building performance of three particular pilot projects is tried to be understood and further discussion about potentials and drivers for PV retrofitting in Egypt is also developed (Dabaieh et al., 2016). It is concluded that local buildings in two different case studies show a high energy performance with rooftop PV system up to 70% electricity saving with passive design strategies supporting PV retrofitting (Dabaieh et al., 2016).

Breyer et al. (2015) investigated the climate change mitigation relevance of PV systems by calculating the avoided GHG emissions for specific representative PV applications such as off-grid, large scale PV power plants and rooftop systems in different regions and concluded that PV systems are a viable and highly attractive climate change mitigation option in terms of both ecology and economy (Breyer et al., 2015).

In this study, considering the building area, four units of solar panels and 15 units of photovoltaic panels are chosen for standard building. It is assumed that electric thermosiphon is used for obtaining domestic hot water in the existing standard building. Instead of the thermosiphon, a system includes two solar panels and a boiler for each apartment is assumed to be able to heat water substantially. In case of insufficient solar energy, hot water is considered to be obtained with the help of electric thermosiphon.

3.4.2. Ground Source heat Pump (Geothermal Heat Pump)

Ground source/geothermal heat pumps are a highly efficient, renewable energy technology for space heating and also cooling. This technology relies on the fact that Earth has a constant temperature at depth which is warmer than the air in winter and cooler than the air in summer. A ground source heat pump system is a central heating or cooling system that transfers heat stored in the Earth into a building during the winter, and transfer heat out of the building during the summer.

A geothermal heat pump includes three principle components, an earth connection subsystem, heat pump subsystem, and heat distribution subsystem. Heat is removed from the earth through a liquid, such as ground water or an antifreeze solution through buried heat collecting pipes, then heat is upgraded by the heat pump, and it is transferred to indoor air (Omer, 2008). The only energy used by ground source heat pump (GSHP) systems is electricity to power the pumps. A typical GSHP system is shown in Figure 3.15.

A GSHP system does not directly create combustion products. It can produce more energy than it uses, as it draws additional free energy from the ground. A GSHP delivers three or four times as much thermal energy (heat) as is used in electrical energy to drive the system (Omer, 2008). Furthermore, the GSHP systems are more efficient than air-source heat pumps, which exchange heat with the outside air, due to the stable, moderate temperature of the ground. They are also more efficient than conventional heating and air-conditioning technologies (Benli and Durmus, 2009).

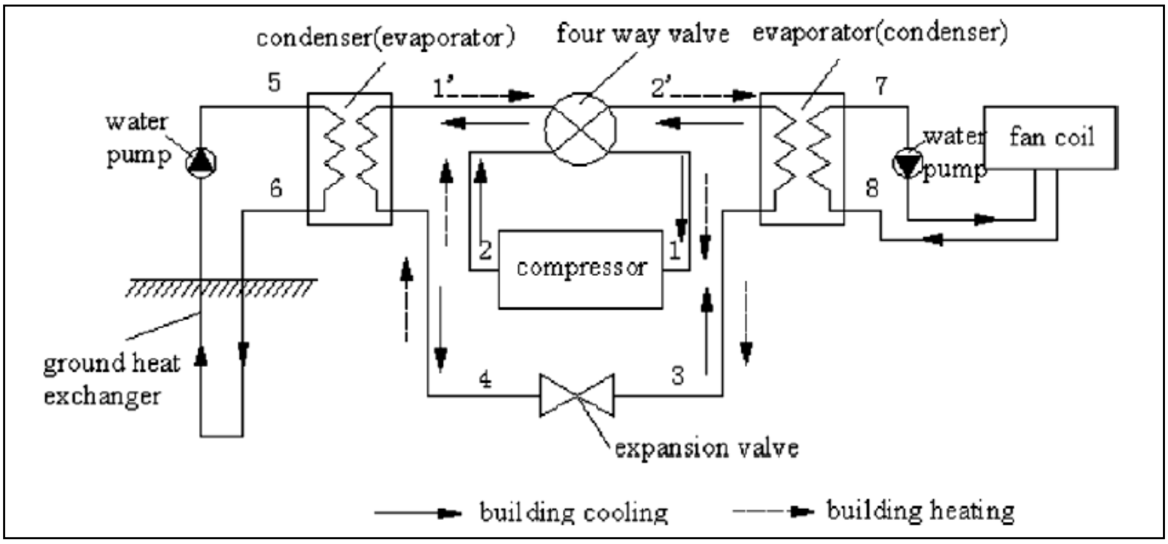


Figure 3.15. Layout of a GSHP system (Bi et al., 2009).

GSHPs cost more to install than conventional systems; however they have lower maintenance costs and can be expected to provide reliable and environmentally friendly heating for in excess of 20 years. Moreover, GSHPs can reduce GHG emissions up to by 66% or more compared with conventional heating and cooling systems that use fossil fuels. In some studies, residential fossil fuel heating systems are found to produce from 1.2 to 36 times the equivalent CO_2 emissions of GSHPs (Omer, 2008). CO_2 emission reductions from 15% to 77% can be achieved through the use of GSHPs as well (Omer, 2008).

Han and Yu (2016) analyzed the performance of a GSHP system installed to provide heat for a three-storey residential building in the Unites States via monitoring data over four-year operation period and concluded that the installed GSHP system provided sufficient heat supply for the building without any need for an auxiliary heater (Han and Yu, 2016).

Liu et al. (2015) investigated the feasibility and performance of ground source heat pump in three cities in cold climate zone of China by simulating the same office building in each city (Liu et al., 2015). They concluded that GSHP displays different performance and therefore feasibility results in each city because of the different meteorological and building envelope thermal characteristics (Liu et al., 2015).

Bakırcı (2010) evaluated the performance of vertical ground-source heat pumps systems for climatic conditions of Erzurum in Turkey and concluded that the system can be efficiently used for residential heating in Erzurum being a cold climate in Turkey (Bakırcı, 2010). He also stated that GSHPs are quite, pollution free with no emissions or harmful exhaust and waste products, do not damage the surrounding landscape and their operating costs are lower than other conventional systems and have a longer life expectancy than that of them (Bakırcı, 2010).

Similarly, Tarnawski et al. (2009) carried out a computer simulation and analysis of a ground source heat pump for a typical residential house with 200 m2 living space located in Sapporo, Japan. They concluded that the ground source heat pump system is more beneficial alternative for space heating than an oil furnace and an electric resistance system (Tarnawski et al., 2009). They also concluded that the heat pump technology offers relatively low thermal degradation of the ground environment, lower cost of heating and cooling, higher operating efficiency than electric resistance heating or air-source heat pump and is environmentally clean with no greenhouse gas emissions (Tarnawski et al., 2009).

In this thesis, instead of gas stoves, a ground source heat pump is chosen and investigated for space heating of the standard building. Since GSHP system can show misleading and also incommensurable performance in sample four cities because of the different meteorological characteristics and poor thermal performance of standard building, standard building is both assumed to have proper insulation and no insulation in four sample cities so that building thermal properties are aligned with related climatic condition to show the dual performance of GSHP system.

3.5. Economic Assessment Method

In addition to technical viability, one of other most critical factors is the economic viability of energy efficient retrofitting of existing buildings. Hence in the present study, simple payback method is adopted to analyze the economic viability of energy efficiency measures. An economic analysis based on initial investment costs, energy consumption costs and annual savings for each energy efficiency measures is undertaken where payback period is adopted as an indicator. Payback period is calculated as follows:

$$payback\ period = \frac{investment\ cost}{saving} \tag{3.1}$$

Payback period in terms of year is obtained by dividing investment cost by annual saving. The shorter the payback period, the more feasible the energy efficiency measure is.

Moreover, net present value (NPV) is also adopted as an in-depth economic analysis tool to analyze the economic viability of energy efficiency measures since payback period method does not take into account time value of money and investment lifetime. NPV is calculated as follows:

$$NPV = \sum_{t=1}^{T} \frac{Ct}{(1+r)^t} - Co \tag{3.2}$$

where Co and Ct are initial investment cost and saving, respectively, t is the time period, T is the lifespan and r is the discount rate. Net present value is positive for feasible energy efficiency measures. The larger the value, the more economically attractive the energy efficiency measure is. The discount rate and lifespan of investments are presumed as 10% (Türkiye Cumhuriyeti Merkez Bankası, 2015) and 30 years (Valdiserri and Biserni, 2016; Penna et al., 2015; Wang and Holmberg, 2015; Friedman et al., 2014), respectively. Additionally, it is assumed that there would be no change in energy prices throughout the lifetime of investments. Maintenance costs are not considered in the study as well.

4. RESULTS AND DISCUSSION

4.1. Technical and Economic Evaluation of Energy Efficiency Measures

4.1.1. Thermal Insulation Measures

Walls of buildings are usually comprised of stones, concrete with reinforced iron bars, concrete bricks, and clay bricks. Structure of walls varies with climate since walls are the largest part of a building which is exposed to outer climatic conditions. In warmer climates, it is sufficient to have walls with bricks and concrete bricks which are only covered with thin plaster layer, whereas in colder climates sandwich walls are usually used. The sandwich wall consists of an insulation layer in the middle of the two brick layers and two plaster layers on the inside and outside surfaces. Similarly, ceilings are made of a plaster layer on bottom, reinforced concrete, and insulation on top. Polystyrene and rock wool materials are usually used as insulation material (Bolatturk, 2006).

It is assumed that existing space heating of standard building is provided by existing stoves which use natural gas in Ankara, Erzurum and Istanbul and bulk LPG (liquid petroleum gas) in Antalya as fuel. For calculations, heat insulation is applied to external walls of the façade and to roof (attic). Rockwool is assumed for roof insulation calculations whereas two different material options are considered for external wall insulation calculations. These materials are XPS (extruded polystyrene) and EPS (expanded polystyrene) and have different costs.

Polystyrene (ρ = 30 kg/m^3, k = 0.030 W/ m K) is chosen as an insulation material in the calculations. The structure of sandwich wall consists of 2 cm inner plaster (k = 0.87 W/m K), 13.5 cm horizontal hollow brick (k = 0.45 W/m K), insulation material, 8.5 cm horizontal hollow brick, and 3 cm external plaster. These properties are used for calculations for standard building located in all cities chosen.

Heat losses from buildings usually occur from external walls, ceiling, windows, and basement and by infiltration. Optimum wall thickness is calculated by considering heat losses from external walls. Heat loss from per unit area of external wall is

$$q = U\,(Tb - To) \tag{4.1}$$

where U is the overall heat transfer coefficient, Tb is base temperature, and To is mean daily temperature. The annual heat loss per unit area can be obtained from

$$qA = 86400\ \mathrm{DD}U \tag{4.2}$$

where DD is the degree-days. The annual energy requirement can be calculated by dividing the annual heat loss to the efficiency of the heating system η_s,

$$E = \frac{86400\ \mathrm{DD}U}{\eta s} \tag{4.3}$$

The wall conductance *U* for a typical wall that includes a layer of insulation is given by

$$U = \frac{1}{Ri+Rw+Rins+Ro} \tag{4.4}$$

where Ri and Ro are the inside and outside air film thermal resistances, respectively, Rw is total thermal resistance of the composite sandwich wall materials without the insulation, and Rins is the thermal resistance of the insulation layer, which is

$$Rins = \frac{x}{k} \tag{4.5}$$

where x and k are the thickness and thermal conductivity of the insulation material, respectively. If Rtw is the total wall thermal resistance excluding the insulation layer resistance, Equation 4.4 can be rewritten as

$$U = \frac{1}{Rtw+Rins} \tag{4.6}$$

As a result, the annual heating load is then given by

$$EA = \frac{86400\ \mathrm{DD}}{(Rtw+\frac{x}{k})\eta s} \tag{4.7}$$

and the annual fuel consumption is

$$mfA = \frac{86400\ \mathrm{DD}}{\left(Rtw + \frac{x}{k}\right) LHV\ \eta s} \tag{4.8}$$

where LHV is lower heating value of the fuel given usually in J/kg, J/m^3 or J/kW h depending on the fuel type.

Insulations calculations for all four cities are carried out according to the assumptions and methods which are defined in TS 825 and Regulation on Building Energy Performance. Thermal insulation thicknesses that are driven by limit values for different climatic regions in TS 825 and Regulation on Building Energy Performance and related insulation cost calculations are shown in Appendix A.

Heating is assumed to be carried out by existing natural gas stove in the standard building in four cities. Insulation is assumed to be applied to only external façade and roof. Annual energy consumption for both insulated and non-insulated cases and related calculations are also given in detail in Appendix A. Firstly, in order to calculate heating energy need, heat loss for non-insulated case is calculated for all four cities by using IZODER’s (The Association of Heat, Water, Acoustic and Fire Insulators) TS 825 calculation tool (İZODER, 2015) which utilizes formulas and limit value calculations of TS 825 and Regulation on Building Energy Performance. Secondly, heat loss that is heating need for insulated case is calculated by the implementation of insulation with related thicknesses. Calculation of heat losses and heating costs for both insulated and non-insulated cases in four cities are shown in detail in Appendix A. Fuel cost values are taken from DOSIDER’s (The Association of Natural Gas Equipment Manufacturers and Businessmen) (DOSİDER, 2015) and PALEN’s (Erzurum Natural Gas Transmission Inc.) (Palen Doğalgaz, 2015) December 2015 database.

For insulation applied for buildings in all four cities, investment cost, annual savings namely difference in energy consumptions and emissions and payback periods are shown in Table 4.1 and Table 4.2.

Table 4.1. Annual energy consumption and emissions difference of thermal insulation.

Fuel type	Province	Annual Energy Consumption (kWh)		Annual CO_2 Emissions (kg eq. CO_2)		Annual Energy Consumption Difference (Energy Saving) (kWh)	Annual CO_2 Emissions Difference (kg eq. CO_2)
		No Insulation	With Insulation	No Insulation	With Insulation		
Natural Gas	Ankara	36143.02	19677.59	8457.47	4604.56	16465.43	3852.91
Bulk LPG	Antalya	14926.46	9094.17	4134.63	2519.09	5832.28	1615.54
Natural Gas	Erzurum	51645.45	23747.50	12085.03	5556.92	27897.95	6528.12
Natural Gas	Istanbul	28200.30	16170.56	6598.87	3783.91	12029.74	2814.96

As it is shown in Table 4.1 largest energy saving in kWh is obtained in Erzurum which is the coldest city among four cities while smallest energy saving amount is obtained in Antalya as being the warmest city. Related CO_2 emissions of energy consumptions for both insulated and non-insulated cases are calculated by using greenhouse gas emission conversion factors of natural gas and bulk LPG which are taken from the Regulation on Building Energy Performance (Official Gazette 05.12.2008, no: 27075) which is also shown in Appendix B.

Table 4.2. Economic assessment of thermal insulation measures.

Province	Annual Energy Consumption (TL)		Annual Energy Consumption Difference (TL)	Insulation (XPS) & Roof (Rockwool)			Insulation (EPS) & Roof (Rockwool)		
	No Insulation	With Insulation		Investment Cost (VAT Included) (TL)	Payback period (year)	NPV (TL)	Investment Cost (VAT Included) (TL)	Payback period (year)	NPV (TL)
Ankara	5394.69	2937.07	2457.62	6835.67	2.78	14847.37	4711.41	1.92	16778.51
Antalya	7021.09	4277.71	2743.38	4205.61	1.53	19687.27	3452.53	1.26	20371.89
Erzurum	7119.92	3273.87	3846.05	7996.48	2.08	25690.82	5291.86	1.38	28149.57
Istanbul	4125.61	2365.70	1759.91	5237.21	2.98	10321.19	3904.81	2.22	11532.46

The results shown in Table 4.2 indicate that when insulation is applied on the external walls and attic payback period of investment is relatively shorter in Antalya and Erzurum since insulation provides great saving amount in kWh and TL in Erzurum as being the coldest city and thus having the largest saving potential and it provides second highest saving amount in TL in Antalya because of higher price of bulk lgp fuel. Similarly, NPV is highest in Erzurum and Antalya, respectively.

4.1.2. Energy Efficient Lighting Measures

In standard building, 22 units of 60 watts and 4 units of 40 watts conventional incandescent lamps and 2 units of 32 watts Ralina lighting fixture are assumed to be used as existing lighting measures. Instead of them, 22 units of 18 watts and 4 units of 13 watts compact florescent lamps and 2 units of 3 watts led lamps are considered as efficient lighting measures in order to reduce energy consumed by lighting.

Average daily functioning hours of lighting appliances are taken from the study of “Energy Efficiency in Lighting and Household Appliances” of General Directorate of Renewable Energy, namely General Directorate of Electrical Power Resources Survey and Development Administration (EIE) (Türkiye Cumhuriyeti Enerji ve Tabii Kaynaklar Bakanlığı Yenilenebilir Enerji Genel Müdürlüğü, 2017a).

Table 4.3 shows the cost of annual energy consumption for both efficient and inefficient cases. The cost of annual energy consumption difference between inefficient and efficient cases namely energy saving in TL is obtained to be 643.54 TL in all cities. Electricity unit price is taken from Republic of Turkey Energy Market Regulatory Authority (EPDK) (Türkiye Cumhuriyeti Enerji Piyasası Denetleme Kurumu, 2016; Akıllı Tarife, 2016).

Table 4.3. Cost of annual energy consumption of lighting appliances.

	Type of lighting appliance	**Electricity unit price (TL/kWh)**	**Lamp power (W)**	**Unit**	**Daily fuctioning hours (h)**	**Cost of annual energy consumption (TL)**
Inefficient case (existing)	60 W Incandescent lamps	0.41	60	22	4	779.33
	40 W Incandescent lamps	0.41	40	4	4	94.46
	Ralina lighting fixture	0.41	32	2	4	37.79
	Total					**911.58**
Efficient case	18 W Compact florescent lamps	0.41	18	22	4	233.80
	13 W Compact florescent lamps	0.41	13	4	4	30.70
	3 W Led lamps	0.41	3	2	4	3.54
	Total					**268.04**
Difference between inefficient and efficient cases						**643.54**

Although cost of annual energy consumption difference between inefficient and efficient cases is found to be 643.54 TL, there is an additional cost for efficient case because of lamp purchase needed and it is investment cost. When total cost of lamp purchases both of inefficient and efficient cases are compared it is observed that there is an additional cost of 101.1 TL for each standard building.

Table 4.4. Cost of lamp purchase.

	Type of lighting appliance	Unit	Cost of annual electricity consumption (TL)	Purchasing cost of one lamp (TL)	Lifetime of a lamp (h)	Annual lamp need (units)	Total cost of lamp purchase (TL)
Inefficient case (existing)	60 W Incandescent lamps	22	779.33	0.45	1000	2	19.80
	40 W Incandescent lamps	4	94.46	0.45	1000	2	3.60
	Ralina lighting fixture	2	37.79	3.00	1000	2	12.00
	Total		**911.58**				**35.40**
Efficient case	18 W Compact florescent lamps	22	233.80	3.25	6000	1	71.50
	13 W Compact florescent lamps	4	30.70	3.25	6000	1	13.00
	3 W Led lamps	2	3.54	26.00	50000	1	52.00
	Total		**268.04**				**136.50**
Difference between inefficient and efficient cases			**643.54**				**-101.10**

Table 4.5. shows annual cost of electricity consumption of lighting and purchasing cost of lighting appliances for both efficient and inefficient cases of standard house. When total cost of lamp purchase is considered total cost difference namely saving in TL is obtained to be 542.44 TL. First investment cost of efficient lamps is calculated to be 136.50 TL and annual energy saving of efficient lamps is calculated to be 542.44 TL. Accordingly, payback period is calculated to be 0.25 years. Hence, payback period of changing incandescent lamps with compact fluorescent and led lamps is found to be nearly 3 months. NPV for all cities is calculated to be 5391 TL.

Table 4.5. Electricity consumption related costs and purchasing costs of lighting.

	Type of lighting appliance	Cost of annual electricity consumption (TL)	Total cost of lamp purchase (TL)	Electricity consumption + Cost of lamp purchase (TL)
Inefficient case (existing)	60 W Incandescent lamps	779.33	19.8	799.13
	40 W Incandescent lamps	94.46	3.6	98.06
	Ralina lighting fixture	37.79	12	49.79
	Total	**911.58**	**35.4**	**946.98**
Efficient case	18 W Compact florescent lamps	233.80	71.5	305.30
	13 W Compact florescent lamps	30.70	13	43.70
	3 W Led lamps	3.54	52	55.54
	Total	**268.04**	**136.5**	**404.54**
Difference between inefficient and efficient cases		**643.54**	**-101.1**	**542.44**

Annual savings namely difference in energy consumptions and emissions of lighting improvement in all four cities are shown in Table 4.6. As it is shown in Table 4.6 energy savings in kWh and emissions are all the same in four cities since lighting improvement is not about degree days and location. Related CO_2 emissions of energy consumptions for both efficient and inefficient cases are calculated by using greenhouse gas emission conversion factors of electricity which is taken from the Regulation on Building Energy Performance (Official Gazette 05.12.2008, no: 27075) which is also shown in Appendix B.

Table 4.6. Annual energy consumption and emissions difference of lighting.

Province	**Annual Energy Consumption (kWh)**		**Annual CO_2 Emissions (kg eq. CO_2)**		**Annual Energy Consumption Difference (Energy Saving) (kWh)**	**Annual CO_2 Emissions Difference (kg eq. CO_2)**
	Inefficient Case	**Efficient Case**	**Inefficient Case**	**Efficient Case**		
Ankara	2223.36	653.76	1371.81	403.37	1569.60	968.44
Antalya	2223.36	653.76	1371.81	403.37	1569.60	968.44
Erzurum	2223.36	653.76	1371.81	403.37	1569.60	968.44
Istanbul	2223.36	653.76	1371.81	403.37	1569.60	968.44

4.1.3. Energy Efficient Appliance Measures

For existing case of the building, (a) low energy performance class appliances (refrigerator, washing machine, cooker with oven, dishwasher, television etc.), (b) electric thermosiphon for heating water, and (c) 2 units of natural gas stove for space heating (one in sofa, other in parents' bedroom) are assumed to be used.

For efficiency improvement, appliances with higher energy performance are assumed to be applied. These appliances include refrigerator, washing machine, cooker with oven and dishwasher. Refrigerator, washing machine, dishwasher and cooker with oven are considered since energy performance class labeling is available only for those appliances in local market. The remaining appliances such as; vacuum cleaner, iron, television, thermosiphon and others are taken as they are, since efficient options (high energy performance) for these are not available in the market. Average values are assumed for functioning hours and functioning days of household appliances. Power values of both efficient and inefficient appliances are taken from product catalogue of brands (Arçelik, 2016a, 2016b, 2016c; Indesit, 2016a, 2016b) in the market and listed in Appendix C. Electricity unit price is taken from Republic of Turkey Energy Market Regulatory Authority (EPDK) (Türkiye Cumhuriyeti Enerji Piyasası Denetleme Kurumu, 2016; Akıllı Tarife, 2016). Accordingly, for both existing inefficient case and efficient case total annual energy consumption and consumption costs of household appliances are shown in Table 4.7 and Table 4.8. Annual electricity consumption of inefficient appliances in the standard building is calculated to be 9161 kWh. If inefficient lighting is also considered, total annual electricity consumption increases to 11384 kWh in the standard building and 5692 kWh in one apartment of the standard building, respectively. If electricity consumption of thermosiphon is excluded, total annual electricity consumption in one apartment of the standard building is found to be 3292 kWh. It is a very similar amount to 3036 kWh (Türkiye Elektrik İletim A.Ş., 2011) which is estimated by Turkish Electricity Transmission Company (TEİAŞ) for annual electricity consumption of a family of four people in Turkey by taking into account electricity consumption of appliances and lighting but not water heating.

Table 4.7. Annual energy consumption and consumption costs of appliances in inefficient existing case.

Appliances	**Grid Electricity unit price (TL/kWh)**	**Inefficient (existing) case**				
		Power of appliance (W)	**Average daily functioning hours (h)**	**Average number of functioning days in a month (day)**	**Annual energy consumed (kWh)**	**Annual cost of consumption (TL)**
Refrigerator	0.41	145.89	24.00	30	1260.49	516.80
Washing machine	0.41	2020.00	1.50	10	363.60	149.08
Dishwasher	0.41	2400.00	1.50	15	648.00	265.68
Cooker with oven	0.41	7000.00	1.50	8	1008.00	413.28
Vacuum cleaner	0.41	3600.00	1.00	8	345.60	141.70
Iron	0.41	2400.00	1.00	8	230.40	94.46
Television	0.41	200.00	6.00	30	432.00	177.12
Thermosiphon	0.41	3810.00	3.50	30	4800.60	1968.25
Miscellaneous	0.41	100.00	2.00	30	72.00	29.52
Total		**21675.89**			**9160.69**	**3755.88**

Table 4.8. Annual energy consumption and consumption costs of appliances in efficient case.

Appliances	**Grid Electricity unit price (TL/kWh)**	**Efficient case**				
		Power of appliance (W)	**Average daily functioning hours (h)**	**Average number of functioning days in a month (day)**	**Annual energy consumed (kWh)**	**Annual cost of consumption (TL)**
Refrigerator	0.41	107.53	24.00	30	929.09	380.93
Washing machine	0.41	1700.00	1.50	10	306.00	125.46
Dishwasher	0.41	2100.00	1.50	15	567.00	232.47
Cooker with oven	0.41	5600.00	1.50	8	806.40	330.62
Vacuum cleaner	0.41	3600.00	1.00	8	345.60	141.70
Iron	0.41	2400.00	1.00	8	230.40	94.46
Television	0.41	200.00	6.00	30	432.00	177.12
Thermosiphon	0.41	3810.00	3.50	30	4800.60	1968.25
Miscellaneous	0.41	100.00	2.00	30	72.00	29.52
Total		**19617.53**			**8489.09**	**3480.53**

Table 4.9 compares the cost of annual energy consumption, the amount of annual energy consumed and CO_2 emissions for both efficient and inefficient cases and shows the difference between these two cases. Related CO_2 emissions of energy consumption for both efficient and inefficient cases are calculated by using greenhouse gas emission conversion factors of electricity which is taken from the Regulation on Building Energy Performance (Official Gazette 05.12.2008, no: 27075) which is also shown in Appendix B. The cost of annual energy consumption difference between inefficient and efficient cases namely energy saving in TL is obtained to be 275.35 TL in all cities.

Table 4.9. Difference between inefficient and efficient cases.

Appliances	**Inefficient (existing) case**			**Efficient case**			**Annual consumption difference between two cases (kWh)**	**Annual consumption difference between two cases (TL)**	**Annual CO_2 emissions difference (kg eq. CO_2)**
	Annual energy consumed (kWh)	**Annual cost of consumption (TL)**	**Annual CO_2 emissions (kg eq. CO_2)**	**Annual energy consumed (kWh)**	**Annual cost of consumption (TL)**	**Annual CO_2 emissions (kg eq. CO_2)**			
Refrigerator	1260.49	516.80	777.72	929.09	380.93	573.25	331.40	135.87	204.47
Washing machine	363.60	149.08	224.34	306.00	125.46	188.80	57.60	23.62	35.54
Dishwasher	648.00	265.68	399.82	567.00	232.47	349.84	81.00	33.21	49.98
Cooker with oven	1008.00	413.28	621.94	806.40	330.62	497.55	201.60	82.66	124.39
Vacuum cleaner	345.60	141.70	213.24	345.60	141.70	213.24	0.00	0.00	0.00
Iron	230.40	94.46	142.16	230.40	94.46	142.16	0.00	0.00	0.00
Television	432.00	177.12	266.54	432.00	177.12	266.54	0.00	0.00	0.00
Thermosiphon	4800.60	1968.25	2961.97	4800.60	1968.25	2961.97	0.00	0.00	0.00
Miscellaneous	72.00	29.52	44.42	72.00	29.52	44.42	0.00	0.00	0.00
Total	**9160.69**	**3755.88**	**5652.15**	**8489.09**	**3480.53**	**5237.77**	**671.60**	**275.35**	**414.37**

More specifically, Table 4.10 compares efficient and inefficient cases focusing on refrigerator, washing machine, dishwasher and cooking with oven to analyze payback period. Comparison is carried out by considering annual energy consumption and consumption cost of appliances for both cases and purchasing cost of efficient appliances.

Table 4.10. Comparison of appliances in inefficient and efficient cases.

Appliances	Inefficient (existing) case		Efficient case		Annual consumption difference between two cases (TL)	Purchasing cost of efficient appliances (Energy Class A) (TL)	Payback period (year)
	Annual energy consumed (kWh)	Annual cost of consumption (TL)	Annual energy consumed (kWh)	Annual cost of consumption (TL)			
Refrigerator	1260.49	516.80	929.09	380.93	135.87	2098.00	15.44
Washing machine	363.60	149.08	306.00	125.46	23.62	1668.00	70.63
Dishwasher	648.00	265.68	567.00	232.47	33.21	1590.00	47.88
Cooker with oven	1008.00	413.28	806.40	330.62	82.66	2190.00	26.50
Total	**3280.09**	**1344.84**	**2608.49**	**1069.48**	**275.35**	**7546.00**	**27.40**

Switching to energy efficient appliances from inefficient appliances decreases electricity consumption cost. However, the amount of this decrease cannot compensate for the investment cost of class A appliances. As a result, longer payback periods are obtained; 15.44 years for refrigerator, 26.50 years for cooker with oven, 47.88 years for dishwasher, 70.63 years for washing machine and 27.4 years on average for all four appliances. NPV for energy efficient appliances (refrigerator, washing machine, dishwasher and cooking with oven) is calculated to be -4500 TL which is a negative value.

As it is shown in Table 4.11 and Table 4.12, although energy efficient appliances have longer payback periods that even exceed life expectancy of appliances and negative NPV, they can still provide 7% energy and emission saving. However, when energy efficient household and lighting appliances are considered together 20% energy saving (kWh), CO_2 emission saving and energy (electricity) consumption cost saving can be obtained in standard building in four cities. 70% of this energy consumption saving is only obtained from energy efficient lighting appliances. This shows the importance of efficient lighting appliances on energy consumption and therefore energy efficiency. Hence, improvement in efficiency of lighting appliances would contribute to overall energy consumption targets much.

Table 4.11. Saving amount of efficient cases with lighting.

	Energy (kwh)	**Energy Cost (TL)**	**CO_2 emissions (kg eq. CO_2)**
Inefficient Case	11384.05	4667.46	7023.96
Efficient Case (with lighting)	9142.85	3748.57	5641.14
Saving (amount)	2241.20	918.89	1382.82
Saving (%)	20%	20%	20%

Table 4.12. Saving amount of efficient cases without lighting.

	Energy (kwh)	**Energy Cost (TL)**	**CO_2 emissions (kg eq. CO_2)**
Inefficient Case	9160.69	3755.88	5652.15
Efficient Case (without lighting)	8489.09	3480.53	5237.77
Saving (amount)	671.60	275.35	414.37
Saving (%)	7%	7%	7%

Since electricity price and appliances are the same for all four cities selected from each degree day regions, results for energy saving (kWh and TL) and CO_2 emissions saving are valid for all four cities.

4.1.4. Renewable Sources of Energy Measures

4.1.4.1. Photovoltaic panels. Fifteen units of photovoltaic panels with 170 Wp are chosen for electricity production with on-grid system. For photovoltaic panels applied to buildings in all four cities annual electricity production, investment costs and related payback periods of investment are shown in Table 4.13. Energy production of photovoltaic panels and cost calculations are given in detail in Appendix D. Technical properties and annual electricity production of photovoltaic panels are obtained from product catalogue of a brand (Permak Company) (Permak, 2016) in the market and stated in Appendix D. Cost of photovoltaic panels are calculated from the data obtained by a supplier (Permak Company) in the market and calculations are shown in Appendix D.

Table 4.13. Annual electricity production and cost of photovoltaic panels.

Cities	**Unit price of electricity (TL/kWh)**	**Investment cost of PV panels (TL)**	**Annual electricity production of PV panels (kWh)**	**Annual energy saving (TL)**	**Annual CO_2 emissions saving (kg eq. CO_2)**	**Payback period (years)**	**NPV (TL)**
Ankara	0.41	30428.68	3250	1332.50	2005.25	22.8	-16243.02
Antalya	0.41	30428.68	3602	1476.82	2222.43	20.6	-15006.21
Erzurum	0.41	30428.68	3313	1358.33	2044.12	22.4	-16021.66
Istanbul	0.41	30428.68	3153	1292.73	1945.40	23.5	-16583.84

Table 4.13 shows the annual savings resulted by producing energy by photovoltaic panels and related payback periods. It is obtained that payback period for photovoltaic panel is around 20 years. The shortest payback period (20.6 years) is obtained in Antalya, whereas the longest one (23.5 years) is obtained in Istanbul. NPV for PV panels is obtained to be negative and calculated to be around -16000 TL in all cities. Table 4.14 shows the energy saving resulted from installing photovoltaic panels in each city. It also shows the reduction of energy need of both efficient and inefficient appliances used in the standard house in all four cities.

Table 4.14. Energy saving resulted from photovoltaic panels usage.

	Annual electricity production of PV panels (kWh)	**Annual energy consumption (kWh)**		**Energy provided by PV (%)**	
		with efficient appliances and lighting	**with inefficient appliances and lighting**	**with efficient appliances and lighting**	**with inefficient appliances and lighting**
Ankara	3250	9143	11384	36%	29%
Antalya	3602	9143	11384	39%	32%
Erzurum	3313	9143	11384	36%	29%
Istanbul	3153	9143	11384	34%	28%

According to Table 4.14 it is observed that photovoltaic panels can provide 28%-32% of energy requirement of standard buildings by themselves in four cities. In case of energy efficient household appliances and lighting fixtures to be used in standard buildings, photovoltaic panels can provide up to 34%-39% of total energy requirement in four cities. Likewise, Table 4.15 shows the CO_2 emissions saving resulted from installing photovoltaic panels in each city. It also shows the ratio of CO_2 emissions reduction of efficient and inefficient appliances and lighting used in the standard building in all four cities. In other words, it is the ratio of CO_2 emissions reduced by using photovoltaic panels to CO_2 emissions produced by the all appliances and shown in Table 4.15 for both efficient and inefficient cases.

Table 4.15. CO_2 emissions saving resulted from photovoltaic panels usage.

	Annual electricity production of PV panels (kWh)	**GHG Emission conversion factor for mixed electricity (kg eq. CO_2/kWh)**	**CO_2 Emissions saving (kg eq. CO_2/year)**	**CO_2 Emissions (kg eq. CO_2)**		**CO_2 Emissions reduction (%)**	
				with efficient appliances and lighting	**with inefficient appliances and lighting**	**with efficient appliances and lighting**	**with inefficient appliances and lighting**
Ankara	3250	0.617	2005.25	5641.14	7023.96	36%	29%
Antalya	3602	0.617	2222.43	5641.14	7023.96	39%	32%
Erzurum	3313	0.617	2044.12	5641.14	7023.96	36%	29%
Istanbul	3153	0.617	1945.40	5641.14	7023.96	34%	28%

It is obtained that photovoltaic panels compensate for 34-39% of electricity consumption of standard building with efficient appliances and lighting whereas they compensate for 28-32% of electricity consumption of standard building with inefficient appliances and lighting. In other words, it is also shown that photovoltaic panels save 34-39% of CO_2 emissions of standard building with efficient appliances and lighting while they save 28-32% of CO_2 emissions of standard building with inefficient appliances and lighting.

According to Table 4.15, the largest amount of electricity is produced in Antalya while the smallest amount is produced in Istanbul. Correspondingly, CO_2 emissions saving amount is largest in Antalya and smallest in Istanbul. Differently from the case of household appliances, different amounts of CO_2 emissions saving are obtained from all cities, since they receive different amounts of solar energy from each other. It can also be concluded that, the percentage of emissions saved by photovoltaic panels is larger for houses in which efficient appliances and lighting is applied since smaller amounts of energy is consumed and therefore smaller amounts of CO_2 emissions are produced in those ones.

As a result, it is obtained that general payback period of photovoltaic panels is more than 20 years even if panels are applied to standard building in different climate zones. Furthermore, the amount of CO_2 emissions from efficient appliances is 20% smaller than that of from inefficient appliances. For instance, for Antalya, using photovoltaic panels saves 39% of CO_2 emissions produced by efficient appliances while it saves 32% of CO_2 emissions produced by inefficient appliances which are nearly 20% smaller.

4.1.4.2. Solar thermal panels for domestic hot water (DHW). For obtaining domestic hot water, it is assumed that electric thermosiphon is used in existing buildings. A system comprises of two solar panels and a boiler for each apartment of the standard house is assumed to be implemented instead of thermosiphon. However, electric termosiphon is still be used in case of insufficient solar energy.

A simulation program of a supplier company (Buderus) is used in calculations of electricity need for heating water and solar energy heating capacity. Solar thermal system configuration, system requirements and calculation results are stated in Appendix E. Average domestic hot water need is assumed to be 200 liters per day for each apartments of the standard house.

Table 4.16 shows the electricity heating support to solar heating of water. Electricity consumption of electric thermosiphon and cost of electricity heating of water for each four climate zones are shown in Table 4.16. Electricity consumption of electric termosiphon is the value calculated using simulation program and thermosiphon power values are obtained from a supplier company (Buderus).

Table 4.16. Electricity heating support to solar heating of water.

	Ankara	**Antalya**	**Erzurum**	**Istanbul**
Electricity consumption of electric termosiphon (1 apartment) (kWh/year)	980.61	628.59	1266.35	1033.06
Electricity consumption of electric termosiphon (2 apartments) (kWh/year)	1961.22	1257.18	2532.70	2066.12
Unit price of electricity (TL/kWh)	0.41	0.41	0.41	0.41
Cost of electricity heating of water (1 apartment) (TL/year)	402.05	257.72	519.20	423.55
Cost of electricity heating of water (2 apartments) (TL/year)	804.10	515.44	1038.41	847.11
Annual energy consumption of solar panels (kWh/year)	1080.00	1080.00	1080.00	1080.00
Total annual energy consumption of solar heating with the support of thermosiphon (kWh/year)	3041.22	2337.18	3612.70	3146.12
Total annual energy consumption of solar heating with the support of thermosiphon (TL/year)	1246.90	958.24	1481.21	1289.91

In the case of all domestic hot water is obtained from electricity, namely thermosiphon, cost of electricity consumed is calculated in Table 4.17. Since thermosiphon usage does not depend on climatic conditions and unit price of electricity is the same for all cities, cost of electricity heating of water is the same for all cities investigated. Table 4.18 shows the cost difference of energy consumption of thermosiphon usage and solar heating usage with the support of thermosiphon. This difference represents the contribution of solar heating hence it is the energy saving resulted from using solar heating for obtaining domestic hot water.

Table 4.17. Cost of heating of all domestic hot water by electricity.

	Ankara	Antalya	Erzurum	Istanbul
Unit price of electricity (TL/kWh)	0.41	0.41	0.41	0.41
Power of thermosiphon (2 apartments) (W)	3180.00	3180.00	3180.00	3180.00
Total annual energy consumption of termosiphon (2 apartments) (kWh)	4800.00	4800.00	4800.00	4800.00
Cost of electricity heating of water (2 apartments) (TL/year)	1968.00	1968.00	1968.00	1968.00

Table 4.18. Energy saving and payback period of solar heating.

		Ankara	Antalya	Erzurum	Istanbul
Cost of electricity heating of water (2 apartments) (TL/year)	**thermosiphon**	1968.00	1968.00	1968.00	1968.00
	solar heating with the support of thermosiphon	1246.90	958.24	1481.21	1289.91
Energy consumption difference (saving) (TL/year)		721.10	1009.76	486.79	678.09
Investment cost (TL) (VAT included)		11858.87	11858.87	11858.87	11858.87
Payback period (year)		16.4	11.7	24.4	17.5
NPV (TL)		-4601.02	-2127.26	-6609.01	-4969.61

Investment cost of solar heating system is calculated from data obtained from market of producers of solar collector systems and shown in Appendix E. Accordingly, payback period of solar water heating system is obtained for all cities via dividing investment cost by energy consumption difference provided by solar heating. Payback periods range from 11.7 to 24.4 years. The shortest payback period is obtained in Antalya case as 11.7 years while the longest payback period is obtained in Erzurum case as 24.4 years. NPV for solar panels is negative in all cities. In accordance with payback periods, the largest NPV is obtained in Antalya whereas the smallest NPV is obtained in Erzurum.

Moreover, annual emissions released are calculated for both thermosiphon and solar heating with the support of thermosiphon cases. Table 4.19 shows emissions resulted from thermosiphon usage in all four cities.

Table 4.19. Emissions resulted from thermosiphon case.

	Total annual energy consumption (kWh)	**Total annual energy consumption (TL)**	**Total annual CO_2 emissions (kg eq. CO_2)**
Ankara	4800	1968	2961.60
Antalya	4800	1968	2961.60
Erzurum	4800	1968	2961.60
Istanbul	4800	1968	2961.60

Emissions resulted from thermosiphon usage for water heating calculated to be the same for all cities since the standard house for all cities and energy consumption amount are the same. For each city, annual emission released is obtained as 2961.60 kg equivalent CO_2. Similarly, Table 4.20 shows the emissions resulted from using solar panels for obtaining hot water and this scenario also considers thermosiphon usage in case of solar panels are insufficient.

Table 4.20. Emissions resulted from solar panel usage with thermosiphon support.

	Total annual energy consumption (kWh)	**Total annual energy consumption (TL)**	**Total annual CO_2 emissions (kg eq. CO_2)**
Ankara	3041.22	1246.90	1876.43
Antalya	2337.18	958.24	1442.04
Erzurum	3612.70	1481.21	2229.04
Istanbul	3146.12	1289.91	1941.16

If Table 4.19 and Table 4.20 are compared, it is observed that emissions released by the use of solar panels are less than the released by the use of thermosiphon and so is the electricity for all cities. Table 4.21 shows the comparison of emissions and energy savings for all cities.

Table 4.21. Comparison of emissions released and energy saved.

	Total annual energy saving (kWh)	**Total annual energy cost saving (TL)**	**Total annual CO_2 emissions reduction (kg eq. CO_2)**	**Saving (energy, energy cost and emissions) (%)**
Ankara	1758.78	721.10	1085.17	37%
Antalya	2462.82	1009.76	1519.56	51%
Erzurum	1187.30	486.79	732.56	25%
Istanbul	1653.88	678.09	1020.44	34%

Table 4.21 shows that by using solar panels, remarkable emissions reduction and energy saving can be achievable for all climatic regions. Maximum saving is observed in Antalya since it is in the first degree day region hence it is easier to heat water by its gained solar energy. However, minimum saving is observed in Erzurum since it is in the fourth degree day region hence it is more difficult to heat water by its gained solar energy.

4.1.4.3. Ground source heat pump. For space heating requirements, a ground source heat pump is used for space heating of the residential building instead of gas stoves. Investment cost of heat pumps for all cities is shown in Table 4.22.

Table 4.22. Investment cost of heat pump.

Cost items	**Investment Cost (TL)**			
	Ankara	**Antalya**	**Erzurum**	**Istanbul**
Floor heating fittings	13911	13126	13911	13387.7
Heat pump fittings	44471.5	31343.9	44471.5	41170.3
Common fittings	1886.4	1886.4	1886.4	1886.4
Total (VAT exluded)	**60268.9**	**46356.3**	**60268.9**	**56444.4**
Total (VAT included)	**71117.3**	**54700.4**	**71117.3**	**66604.4**

In ground source heat pump application, depending on varying capacity needs there are differences in vertical drilling length, length of pipe to be laid and capacity of appliances for all cities. Hence all of these lead to differences in cost of investment. Same appliances are supposed to be used in Ankara, Erzurum and Istanbul while drilling length in Istanbul is supposed to be the shortest among these three cities. The appliance used in Antalya is supposed to be the one with the smallest capacity and the vertical drilling length is the shortest. Heat pump system configuration and capacity calculations as well as related investment cost calculations for all four cities are stated in detail in Appendix F.

For all cities, energy source for ground heat pump is supposed to be electricity. Table 4.23 summarizes annual energy consumption, annual cost of energy consumption and annual emissions of heat pump for the insulated building in all four cities. Likewise, Table 4.24 summarizes annual energy consumption, annual cost of energy consumption and annual emissions of heat pump for the non-insulated building in all four cities.

Table 4.23. Energy consumption of heat pump in the insulated building.

	Ankara	**Antalya**	**Erzurum**	**Istanbul**
Unit price of electricity (TL/kWh)	0.41	0.41	0.41	0.41
Power of heat pump (W)	9000.00	5000.00	9000.00	9000.00
Annual energy need for heating the insulated building (kWh)	19677.59	9094.17	23747.50	16170.56
COP (Coefficient of performance)	3.25	3.25	3.25	3.25
Efficiency of the heat pump (%)	0.99	0.99	0.99	0.99
Annual energy consumption (kWh)	6115.80	2826.47	7380.73	5025.82
Annual cost of energy consumption (TL)	2507.48	1158.85	3026.10	2060.58
Annual CO_2 emissions (kg equivalent CO_2/year)	3773.45	1743.93	4553.91	3100.93

Table 4.24. Energy consumption of heat pump in the non-insulated building.

	Ankara	**Antalya**	**Erzurum**	**Istanbul**
Unit price of electricity (TL/kWh)	0.41	0.41	0.41	0.41
Power of heat pump (W)	9000.00	5000.00	9000.00	9000.00
Annual energy need for heating the non-insulated building (kWh)	36143.02	14926.46	51645.45	28200.30
COP (Coefficient of performance)	3.25	3.25	3.25	3.25
Efficiency of the heat pump (%)	0.99	0.99	0.99	0.99
Annual energy consumption (kWh)	11233.26	4639.15	16051.42	8764.66
Annual cost of energy consumption (TL)	4605.64	1902.05	6581.08	3593.51
Annual CO_2 emissions (kg equivalent CO_2/year)	6930.92	2862.35	9903.73	5407.80

Electricity unit price is taken from General Directorate of Electrical Power Resources Survey and Development Administration of Turkey (EIE) (Türkiye Cumhuriyeti Enerji Piyasası Denetleme Kurumu; 2016; Akıllı Tarife, 2016). Power, COP values and other technical specifications of heat pump are gathered from the producer firms. Since a heat pump with smaller capacity would be used in Antalya, the smallest energy need for heating is calculated in Antalya. Accordingly, largest cost of electrical energy consumption is calculated in Erzurum and Antalya while the smallest cost is obtained in Antalya. Additionally, in non-insulated case electrical energy consumption gets higher in all cities as energy need increases.

Annual cost of energy consumption in terms of (kWh) and (TL) and annual CO_2 emissions for heat pump for the insulated building is calculated in Table 4.25, Table 4.26 and Table 2.27. Calculation of annual energy consumption of heat pump is shown in detail in Appendix G.

Table 4.25. Comparison of energy consumption (kWh) of heat pump in the insulated building.

Cities	**Annual energy consumption of heat pump (kWh)**	**Annual energy need in the insulated building (kWh)**	**Annual energy saving (kWh)**	**Saving kWh (%)**
Ankara	6115.80	19677.59	13561.79	69%
Antalya	2826.47	9094.17	6267.70	69%
Erzurum	7380.73	23747.50	16366.77	69%
Istanbul	5025.82	16170.56	11144.74	69%

Table 4.26. Comparison of CO_2 emissions of heat pump in the insulated building.

Cities	**Annual CO_2 emissions of heat pump (kg eq. CO_2)**	**Annual CO_2 emissions in the insulated building (kg eq. CO_2)**	**Annual difference (kg eq. CO_2)**	**Saving CO_2 (%)**
Ankara	3773.45	4604.56	831.11	18%
Antalya	1743.93	2519.09	775.15	31%
Erzurum	4553.91	5556.92	1003.00	18%
Istanbul	3100.93	3783.91	682.98	18%

Table 4.27. Comparison of energy consumption (TL) of heat pump in the insulated building.

Cities	**Annual energy consumption of heat pump (TL)**	**Annual energy need in the insulated building (TL)**	**Annual energy saving (TL)**	**Saving TL (%)**	**Investment cost (TL)**	**Payback period (yrs)**	**NPV (TL)**
Ankara	2507.48	2937.07	429.59	15%	71117.30	166	-60970.56
Antalya	1158.85	4277.71	3118.86	73%	54700.43	18	-22999.32
Erzurum	3026.10	3273.87	247.77	8%	71117.30	287	-62528.74
Istanbul	2060.58	2365.70	305.11	13%	66604.39	218	-57934.65

Likewise, annual cost of energy consumption in terms of (kWh) and (TL) and annual CO_2 emissions for heat pump for non-the insulated building is calculated in Table 4.28, Table 4.29 and Table 4.30.

Table 4.28. Comparison of energy consumption (kWh) of heat pump in the non-insulated building.

Cities	Annual energy consumption of heat pump (kWh)	Annual energy need in the non-insulated building (kWh)	Annual energy saving (kWh)	Saving kWh (%)
Ankara	11233.26	36143.02	24909.76	69%
Antalya	4639.15	14926.46	10287.31	69%
Erzurum	16051.42	51645.45	35594.03	69%
Istanbul	8764.66	28200.30	19435.64	69%

Table 4.29. Comparison of CO_2 emissions of heat pump in the non-insulated building.

Cities	Annual CO_2 emissions of heat pump (kg eq. CO_2)	Annual CO_2 emissions in the non-insulated building (kg eq. CO_2)	Annual difference (kg eq. CO_2)	Saving CO_2 (%)
Ankara	6930.92	8457.47	1526.54	18%
Antalya	2862.35	4134.63	1272.27	31%
Erzurum	9903.73	12085.03	2181.31	18%
Istanbul	5407.80	6598.87	1191.07	18%

Table 4.30. Comparison of energy consumption (TL) of heat pump in the non-insulated building.

Cities	Annual energy consumption of heat pump (TL)	Annual energy need in the non-insulated building (TL)	Annual energy saving (TL)	Saving TL (%)	Investment cost (TL)	Payback period (yrs)	NPV (TL)
Ankara	4605.64	5394.69	789.05	15%	71117.30	90	-57890.00
Antalya	1902.05	7021.09	5119.04	73%	54700.43	11	-5857.86
Erzurum	6581.08	7119.92	538.84	8%	71117.30	132	-60034.30
Istanbul	3593.51	4125.61	532.10	13%	66604.39	125	-55989.40

In case of insulation is applied to the standard building, the energy needed for heating is lower than that of non-insulated case in all four cities. Additionally, electrical energy consumption by heat pump is higher in non-insulated case compared to insulated case. Inexistence of insulation leads to larger annual energy saving in terms of TL and kWh and also CO_2 emissions. However, the percentage of saving is the same for each case because of the proportionality between heating energy need and electrical energy consumption of heat pump. Heat pump is more efficient in non-insulated case since it can result in larger saving amount and hence shorter payback period. However, implementing insulation to an non-insulated building before installing heat pump would be a more efficient option since it requires lower investment cost and results in considerable amount of saving and shorter payback period.

Moreover, in the cases of natural gas is used as fuel type, heat pump does not seem as an economic application to be adopted as longer payback periods are obtained even if insulation is not considered. Since LPG used in Antalya is more expensive than natural gas, heat pump seems more efficient than other cities in terms of annual saving (TL) and payback period. However, since the investment cost of heat pump is significantly high, it may not be affordable to adopt this technology.

According to Table 4.29, minimum amount of emissions are released in Antalya, whereas maximum amount of emissions are released in Erzurum as a result of heat pump usage. If carbon emissions are to be considered, investing in heat pump in Antalya seems more feasible than investing in other three cities. In terms of emissions released, the investment does not seem very efficient for all cities though. However, the investment is more efficient in terms of energy savings for all cities.

To be able to compare heat pump and gas stove, annual energy consumption, annual energy consumption cost and annual emissions of gas stove calculations for both insulated and non-insulated building are stated in Table 4.31 and Table 4.32 respectively.

Table 4.31. Energy consumption of gas stove in the insulated building.

	Ankara	**Antalya**	**Erzurum**	**Istanbul**
Annual energy need in the insulated building (kWh)	19677.59	9094.17	23747.50	16170.56
Efficiency of the appliance (stove) (%)	0.85	0.92	0.85	0.85
Annual energy consumption of stove (kWh)	23150.11	9884.97	27938.24	19024.19
Annual energy consumption of stove (TL)	2937.07	4277.71	3273.87	2365.70
Annual CO_2 emissions of stove (kg equivalent CO_2/year)	5417.12	2738.14	6537.55	4451.66

Table 4.32. Energy consumption of gas stove in the non-insulated building.

	Ankara	**Antalya**	**Erzurum**	**Istanbul**
Annual energy need in the non-insulated building (kWh)	36143.02	14926.46	51645.45	28200.30
Efficiency of the appliance (stove) (%)	0.85	0.92	0.85	0.85
Annual energy consumption of stove (kWh)	42521.20	16224.41	60759.35	33176.82
Annual energy consumption of stove (TL)	5394.69	7021.09	7119.92	4125.61
Annual CO_2 emissions of stove (kg equivalent CO_2/year)	9949.96	4494.16	14217.69	7763.38

If Table 4.23 and Table 4.31 are compared, it is observed that energy consumed and emissions released by the use of ground source heat pump are less than that of gas stove in insulated building for all cities. Table 4.33 and Table 4.34 show the comparison.

Table 4.33. Comparison of energy consumed and emissions released by heat pump and gas stove in the insulated building.

	Total annual energy saving (kWh)	**Total annual energy cost saving (TL)**	**Total annual CO_2 emissions reduction (kg eq. CO_2)**
Ankara	17034.30	429.59	1643.68
Antalya	7058.50	3118.86	994.20
Erzurum	20557.50	247.77	1983.64
Istanbul	13998.37	305.11	1350.73

Table 4.34. Comparison of energy consumed and emissions released by heat pump and gas stove in the insulated building in percentage.

	Total annual energy saving (%)	**Total annual energy cost saving (%)**	**Total annual CO_2 emissions reduction (%)**
Ankara	74%	15%	30%
Antalya	71%	73%	36%
Erzurum	74%	8%	30%
Istanbul	74%	13%	30%

If Table 4.24 and Table 4.32 are compared, it is observed that energy consumed and emissions released by the use of ground source heat pump are less than that of gas stove in non-insulated building for all cities. Table 4.35 and Table 4.36 show the comparison.

Table 4.35. Comparison of energy consumed and emissions released by heat pump and gas stove in the non-insulated building.

	Total annual energy saving (kWh)	**Total annual energy cost saving (TL)**	**Total annual CO_2 emissions reduction (kg eq. CO_2)**
Ankara	31287.94	789.05	3019.04
Antalya	11585.26	5119.04	1631.81
Erzurum	44707.93	538.84	4313.96
Istanbul	24412.16	532.10	2355.58

Table 4.36. Comparison of energy consumed and emissions released by heat pump and gas stove in the non-insulated building in percentage.

	Total annual energy saving (%)	**Total annual energy cost saving (%)**	**Total annual CO_2 emissions reduction (%)**
Ankara	74%	15%	30%
Antalya	71%	73%	36%
Erzurum	74%	8%	30%
Istanbul	74%	13%	30%

If heat pump and gas stove are compared with each other, it is observed that energy consumed and emissions released by the use of ground source heat pump are less than that of gas stove in both insulated and non-insulated buildings for all cities. Table 4.35 and Table 4.36 show that heat pump causes about 30% less emissions and 70% less energy consumption than that of stove does for all cities. The smallest energy cost saving ratio is obtained in Erzurum whereas the largest emissions saving ratio is obtained in Antalya.

All in all, even if heat pump has a significant payback period, it is a more environmentally friendly (30% less emissions) way of space heating than gas stove in terms of emissions released.

4.2. Assessment of Findings

4.2.1. Assessment and Comparison of Savings

Annual savings in terms of energy (kWh), energy cost (TL) and CO_2 emissions (kg eq. CO_2) are all summarized both in amount and percentage for each energy efficiency measure and for each city and are shown in Table 4.37-40. Table 4.37 and Figure 4.1 show that insulation and ground source heat pump measures save considerable amount of energy (kWh) while energy efficient appliances save moderate amount of energy. PV panels and insulation measures achieve higher amount of carbon emission reduction, whereas energy efficient lighting and appliances result in lower amount of emission reduction. When energy efficiency measures are compared in terms of energy cost (TL) saving, it is concluded that insulation and PV panels result in higher saving amounts. However, ground source heat pump measure achieves highest energy cost saving amount in Antalya unlike other measures. Moreover, Table 4.38 and Figure 4.2 show that energy efficient lighting achieves the highest saving ratio (71%) among all measures while energy efficient appliances result in the lowest saving ratio (7%). Similar to its performance about energy cost saving amount, ground source heat pump measure achieves highest energy cost saving ratio (73%) in Antalya as well. Ground source heat pump measure also results in very high saving ratio (69%) in all four cities. Saving amounts of energy efficiency measures can be compared separately for each energy cost, energy and carbon reduction targets. Hence, for instance carbon saving comparison can be considered if carbon reduction targets are of top priority for a decision maker whereas energy cost comparison can be essential if financial considerations have priority over other issues.

Furthermore, to be able to evaluate the efficiency of an energy efficiency measure, investment cost and payback period should also be considered besides its saving amount and/or ratio. In this context, although energy, energy cost and carbon emission savings of lighting are not that much high compared to that of other measures, in addition to its highest saving ratio it has the lowest investment cost and shortest payback period (0.25 years) among all the measures which makes it the most cost efficient and applicable measure in terms of technical and economic feasibility.

Additionally, insulation has also shorter payback period (1.26-2.22 years) compared to other measures while ground source heat pump has highest investment cost and longest payback period (around 100 years). In Antalya, despite the high investment cost ground source heat pump performs better and results in considerable amount of energy cost saving and a shorter payback period (10.69

years). Since ground source heat pump is considered as an alternative to the conventional fuels and heating systems, fuel prices directly affect the cost efficiency of ground source heat pump. Unit fuel price in Antalya is the highest among in the other cities hence better energy cost saving and payback period results are obtained compared to that of other cities. As a result, ground source heat pump seems to be more feasible and preferable in areas which have higher fuel prices. Additionally, despite their higher investment costs ground source heat pumps have lower maintenance costs and longer life expectancy compared to conventional systems. However, life cycle costs are not considered in the scope of this thesis.

What is more, PV panels save more energy, energy cost and carbon than solar panels do, however they need higher investment cost and have longer payback period compared to solar panels which makes them less feasible than solar panels. Except the case in Erzurum, most of the time solar panels have payback periods shorter than 20 years. On the other hand, payback periods of PV panels are around 20 years that makes this measure arguable in terms of financial feasibility. PV panels and ground source heat pumps require high investment costs since they require imported technology and the investment depends on foreign currency, hence despite their remarkable saving amounts these measures are obtained to be infeasible. Moreover, energy efficient appliances are not seemed to be a cost and energy effective measure with their lowest saving amounts and high payback periods (27.40 years) which are longer than 20 years. This is because the cost of energy consumption difference between Class A (efficient) and Class B (inefficient) appliances is not sufficient to compensate the investment cost of Class A appliances in a shorter time period. This makes upgrading from Class B to Class A appliances not to be that much feasible.

On the other hand, when NPV of energy efficiency measures are compared with each other, it is observed that only insulation (11532 TL-28150 TL) and lighting (5391 TL) have positive values whereas all other measures have negative NPVs. Despite the shortest payback period of lighting, the largest NPV is obtained by insulation in all cities. NPV of insulation is the largest in Erzurum (28150 TL) and Erzurum is followed by Antalya (20372 TL), Ankara (16779 TL) and Istanbul (11532 TL), respectively.

Comparison criterion among energy efficiency measures can be savings (energy, energy cost and carbon) if a budget is not considered and environmental benefits are prioritized. However, the criterion can be payback period of investment cost if there is a limited and defined budget and financial benefits are prioritized. For instance, carbon saving comparison can be considered if carbon reduction targets are of top priority for a decision maker whereas energy cost comparison can be essential if financial considerations have priority over other issues. The former case results in adopting all energy efficiency measures or selection among them with highest saving amount of targeted saving type such as energy and carbon. The latter case force decision maker of investment to make prioritization among energy efficiency measures starting from the lowest payback period. Therefore if a budget is defined, which is the case most of the time, the most feasible energy efficiency measures are expected to be adopted.

Table 4.37. Annual saving amount of each energy efficiency measure.

Insulation (EPS) & Roof (Rockwool)						
	Energy Cost (TL)	**Energy (kwh)**	**CO_2 Emissions (kg eq. CO_2)**	**Investment Cost (VAT Included) (TL)**	**Payback period (year)**	**NPV (TL)**
Ankara	2457.62	16465.43	3852.91	4711.41	1.92	16779
Antalya	2743.38	5832.28	1615.54	3452.53	1.26	20372
Erzurum	3846.05	27897.95	6528.12	5291.86	1.38	28150
Istanbul	1759.91	12029.74	2814.96	3904.81	2.22	11532
Energy Efficient Lighting						
	Energy Cost (TL)	**Energy (kwh)**	**CO_2 Emissions (kg eq. CO_2)**	**Investment Cost (VAT Included) (TL)**	**Payback period (year)**	**NPV (TL)**
Ankara	643.54	1569.60	968.44	136.50	0.25	5391
Antalya	643.54	1569.60	968.44	136.50	0.25	5391
Erzurum	643.54	1569.60	968.44	136.50	0.25	5391
Istanbul	643.54	1569.60	968.44	136.50	0.25	5391
Energy Efficient Appliances						
	Energy Cost (TL)	**Energy (kwh)**	**CO_2 Emissions (kg eq. CO_2)**	**Investment Cost (VAT Included) (TL)**	**Payback period (year)**	**NPV (TL)**
Ankara	275.35	671.60	414.37	7546.00	27.40	-4500
Antalya	275.35	671.60	414.37	7546.00	27.40	-4500
Erzurum	275.35	671.60	414.37	7546.00	27.40	-4500
Istanbul	275.35	671.60	414.37	7546.00	27.40	-4500
PV Panels						
	Energy Cost (TL)	**Energy (kwh)**	**CO_2 Emissions (kg eq. CO_2)**	**Investment Cost (VAT Included) (TL)**	**Payback period (year)**	**NPV (TL)**
Ankara	1332.50	3250.00	2005.25	30428.68	22.84	-16243
Antalya	1476.82	3602.00	2222.43	30428.68	20.60	-15006
Erzurum	1358.33	3313.00	2044.12	30428.68	22.40	-16022
Istanbul	1292.73	3153.00	1945.40	30428.68	23.54	-16584
Solar Panels						
	Energy Cost (TL)	**Energy (kwh)**	**CO_2 Emissions (kg eq. CO_2)**	**Investment Cost (VAT Included) (TL)**	**Payback period (year)**	**NPV (TL)**
Ankara	721.10	1758.78	1085.17	11858.87	16.45	-4601
Antalya	1009.76	2462.82	1519.56	11858.87	11.74	-2127
Erzurum	486.79	1187.30	732.56	11858.87	24.36	-6609
Istanbul	678.09	1653.88	1020.44	11858.87	17.49	-4970
Ground Source Heat Pump						
	Energy Cost (TL)	**Energy (kwh)**	**CO_2 Emissions (kg eq. CO_2)**	**Investment Cost (VAT Included) (TL)**	**Payback period (year)**	**NPV (TL)**
Ankara	789.05	24909.76	1526.54	71117.30	90.13	-57890
Antalya	5119.04	10287.31	1272.27	54700.43	10.69	-5858
Erzurum	538.84	35594.02	2181.31	71117.30	131.98	-60034
Istanbul	532.10	19435.64	1191.07	66604.39	125.17	-55989

Figure 4.1. Annual saving amount of each energy efficiency measure.

Table 4.38. Annual saving percentage of each energy efficiency measure.

Insulation (EPS) & Roof (Rockwool)						
	Energy Cost (%)	**Energy (%)**	**CO_2 Emissions (%)**	**Investment Cost (VAT Included) (TL)**	**Payback period (year)**	**NPV (TL)**
Ankara	46%	46%	46%	4711.41	1.92	16779
Antalya	39%	39%	39%	3452.53	1.26	20372
Erzurum	54%	54%	54%	5291.86	1.38	28150
Istanbul	43%	43%	43%	3904.81	2.22	11532
Energy Efficient Lighting						
	Energy Cost (%)	**Energy (%)**	**CO_2 Emissions (%)**	**Investment Cost (VAT Included) (TL)**	**Payback period (year)**	**NPV (TL)**
Ankara	71%	71%	71%	136.50	0.25	5391
Antalya	71%	71%	71%	136.50	0.25	5391
Erzurum	71%	71%	71%	136.50	0.25	5391
Istanbul	71%	71%	71%	136.50	0.25	5391
Energy Efficient Appliances						
	Energy Cost (%)	**Energy (%)**	**CO_2 Emissions (%)**	**Investment Cost (VAT Included) (TL)**	**Payback period (year)**	**NPV (TL)**
Ankara	7%	7%	7%	7546.00	27.40	-4500
Antalya	7%	7%	7%	7546.00	27.40	-4500
Erzurum	7%	7%	7%	7546.00	27.40	-4500
Istanbul	7%	7%	7%	7546.00	27.40	-4500
PV Panels						
	Energy Cost (%)	**Energy (%)**	**CO_2 Emissions (%)**	**Investment Cost (VAT Included) (TL)**	**Payback period (year)**	**NPV (TL)**
Ankara	29%	29%	29%	30428.68	22.84	-16243
Antalya	32%	32%	32%	30428.68	20.60	-15006
Erzurum	29%	29%	29%	30428.68	22.40	-16022
Istanbul	28%	28%	28%	30428.68	23.54	-16584
Solar Panels						
	Energy Cost (%)	**Energy (%)**	**CO_2 Emissions (%)**	**Investment Cost (VAT Included) (TL)**	**Payback period (year)**	**NPV (TL)**
Ankara	37%	37%	37%	11858.87	16.45	-4601
Antalya	51%	51%	51%	11858.87	11.74	-2127
Erzurum	25%	25%	25%	11858.87	24.36	-6609
Istanbul	34%	34%	34%	11858.87	17.49	-4970
Ground Source Heat Pump						
	Energy Cost (%)	**Energy (%)**	**CO_2 Emissions (%)**	**Investment Cost (VAT Included) (TL)**	**Payback period (year)**	**NPV (TL)**
Ankara	15%	69%	18%	71117.30	90.13	-57890
Antalya	73%	69%	31%	54700.43	10.69	-5858
Erzurum	8%	69%	18%	71117.30	131.98	-60034
Istanbul	13%	69%	18%	66604.39	125.17	-55989

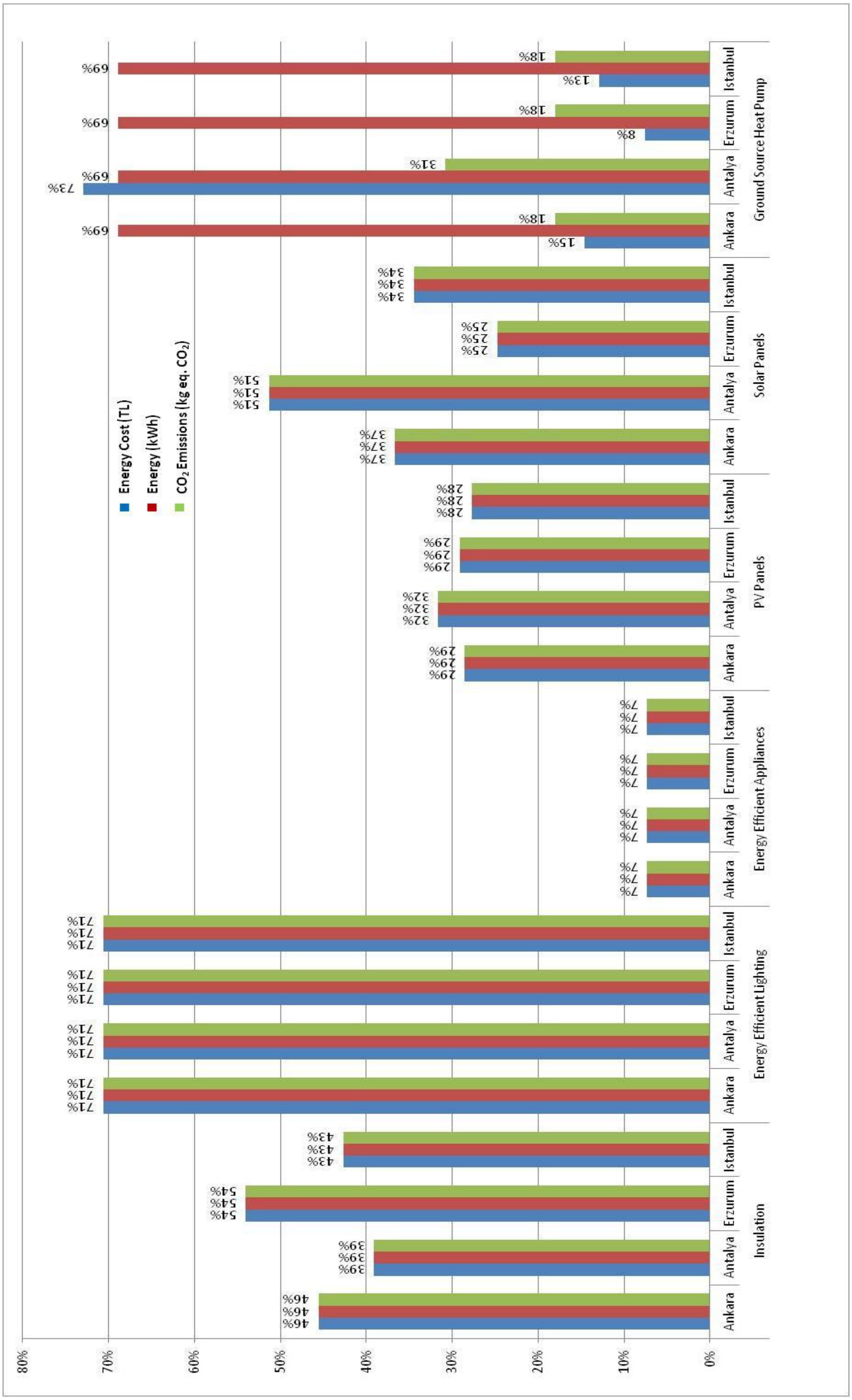


Figure 4.2. Annual saving percentage of each energy efficiency measure.

Figure 4.3-4 and Table 4.39-40 show the total annual savings in terms of energy (kWh), energy cost (TL) and CO_2 emissions (kg eq. CO_2) of the standard building in each city. As it is displayed in Figure 4.3, when all energy efficiency measures are implemented together highest energy (kWh) and carbon emission savings potential are obtained in Erzurum while highest energy cost (TL) saving potential is obtained in Antalya.

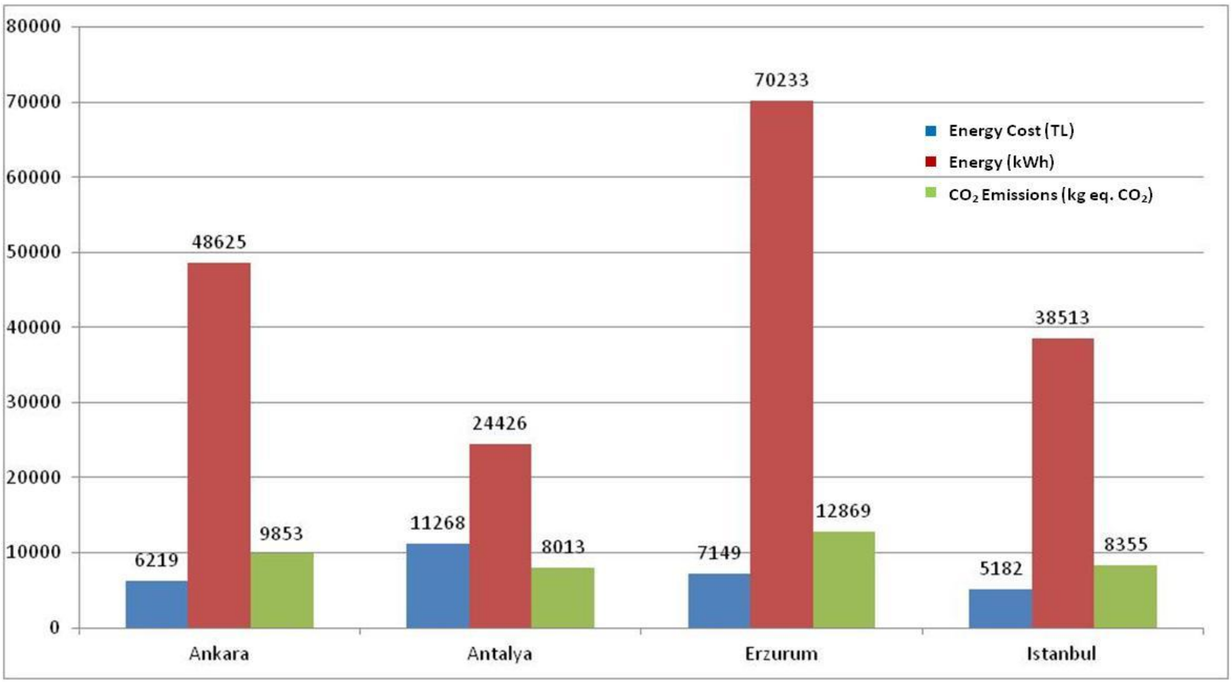


Figure 4.3. Total annual saving potential of the standard building in each city.

Table 4.39 shows the total annual saving potential of each energy efficiency measure individually in sum of four cities. For four cities together, insulation has the largest potential in terms of energy cost and carbon emissions savings, and ground source heat pump has the largest potential in terms of energy saving while PV panels has the third largest potential in terms of energy cost and energy and the second largest potential in terms of carbon emissions. In four cities together, with a total investment cost of 480780 TL, energy cost saving of 29818 TL, energy saving of 181798 kWh and carbon emission saving of 39089 kg eq. CO_2 can be obtained.

Table 4.39. Sum of annual savings in four cities.

	Energy Cost (TL)	Energy (kwh)	CO_2 Emissions (kg eq. CO_2)	Investment Cost (VAT Included) (TL)	Payback period for Investment (year)
Insulation (EPS) & Roof (Rockwool)	10806.96	62225.40	14811.53	17360.61	1.61
Energy Efficient Lighting	2574.14	6278.40	3873.77	546.00	0.21
Energy Efficient Appliances	1101.42	2686.38	1657.50	30184.00	27.40
PV Panels	5460.38	13318.00	8217.21	121714.73	22.29
Solar Panels	2895.74	7062.78	4357.74	47435.48	16.38
Ground Source Heat Pump	6979.03	90226.73	6171.20	263539.43	37.76
Total	29817.67	181797.69	39088.94	480780.25	16.12

According to Table 4.40 and Figure 4.4, when cities are evaluated separately, it is observed that in case of all energy efficiency measures to be applied an investment cost of about 108000 TL – 125000 TL in total is needed for each building in each city. With this investment cost, energy cost saving of 5182 – 11268 TL, energy saving of 24426 – 70233 kWh and carbon emission saving of 8013 – 12869 kg eq. CO_2 can be achieved in the standard building in each city. In Ankara, energy cost saving of 6219 TL, energy saving of 48625 kWh and carbon emission saving of 9853 kg eq. CO_2 can be obtained with an investment cost of 125799 TL and a payback period of 20.2 years is calculated. In Antalya, energy cost saving of 11268 TL, energy saving of 24426 kWh and carbon emission saving of 8013 kg eq. CO_2 can be obtained with an investment cost of 108123 TL and a payback period of 9.6 years is calculated. In Erzurum, energy cost saving of 7149 TL, energy saving of 70233 kWh and carbon emission saving of 12869 kg eq. CO_2 can be obtained with an investment cost of 126379 TL and a payback period of 17.7 years is calculated. In Istanbul, energy cost saving of 5182 TL, energy saving of 38513 kWh and carbon emission saving of 8355 kg eq. CO_2 can be obtained with an investment cost of 120479 TL and a payback period of 23.3 years is calculated. Table 4.40 and Figure 4.4 also show that insulation is the energy efficiency measure which has the highest energy cost saving potential in Ankara, Erzurum and Istanbul while ground source heat pump is the measure that has the highest energy cost saving potential in Antalya. Solar panels and PV panels achieve shortest payback period in Antalya.

If comparison criterion is energy cost savings, the energy efficiency measures with the highest saving potential are obtained by sorting the savings of each energy efficiency measure in descending order for each city. The same is applied for energy and carbon savings as well if they are the comparison criterion. All energy efficiency measures or at least the ones with highest savings that will meet saving goals can be chosen to be adopted if a budget is not considered. For instance in Ankara energy cost saving order is obtained to be as follows: (a) insulation-2458 TL, (b) PV panels-1333 TL, (c) ground source heat pump-789 TL, (d) solar panels-721 TL, (e) energy efficient lighting-644 TL and (f) energy efficient appliances-275 TL. However, carbon saving order in Antalya is obtained to be as follows: (a) PV panels-2222 kg eq. CO_2, (b) insulation-1616 kg eq. CO_2, (c) solar panels-1520 kg eq. $CO_{2,}$ (d) ground source heat pump-1272 kg eq. $CO_{2,}$ (e) energy efficient lighting-968 kg eq. CO_2, (f) energy efficient appliances-414 kg eq. $CO_{2.}$ All sorted energy efficiency measures for all cities according to related saving types are listed in Appendix H.

Table 4.40. Annual savings of the standard building in each city.

Ankara					
	Energy Cost (TL)	**Energy (kwh)**	**CO_2 Emissions (kg eq. CO_2)**	**Investment Cost (VAT Included) (TL)**	**Payback period for Investment (year)**
Insulation (EPS) & Roof (Rockwool)	2457.62	16465.43	3852.91	4711.41	1.92
Energy Efficient Lighting	643.54	1569.60	968.44	136.50	0.25
Energy Efficient Appliances	275.35	671.60	414.37	7546.00	27.40
PV Panels	1332.50	3250	2005.25	30428.68	22.84
Solar Panels	721.10	1758.78	1085.17	11858.87	16.45
Ground Source Heat Pump	789.05	24909.76	1526.54	71117.30	90.13
Total	6219.16	48625.16	9852.69	125798.77	20.23
Antalya					
	Energy Cost (TL)	**Energy (kwh)**	**CO_2 Emissions (kg eq. CO_2)**	**Investment Cost (VAT Included) (TL)**	**Payback period for Investment (year)**
Insulation (EPS) & Roof (Rockwool)	2743.38	5832.28	1615.54	3452.53	1.26
Energy Efficient Lighting	643.54	1569.60	968.44	136.50	0.25
Energy Efficient Appliances	275.35	671.60	414.37	7546.00	27.40
PV Panels	1476.82	3602	2222.43	30428.68	20.60
Solar Panels	1009.76	2462.82	1519.56	11858.87	11.74
Ground Source Heat Pump	5119.04	10287.31	1272.27	54700.43	10.69
Total	11267.89	24425.61	8012.63	108123.02	9.60
Erzurum					
	Energy Cost (TL)	**Energy (kwh)**	**CO_2 Emissions (kg eq. CO_2)**	**Investment Cost (VAT Included) (TL)**	**Payback period for Investment (year)**
Insulation (EPS) & Roof (Rockwool)	3846.05	27897.95	6528.12	5291.86	1.38
Energy Efficient Lighting	643.54	1569.60	968.44	136.50	0.25
Energy Efficient Appliances	275.35	671.60	414.37	7546.00	27.40
PV Panels	1358.33	3313	2044.12	30428.68	22.40
Solar Panels	486.79	1187.30	732.56	11858.87	24.36
Ground Source Heat Pump	538.84	35594.02	2181.31	71117.30	131.98
Total	7148.90	70233.47	12868.93	126379.22	17.68
Istanbul					
	Energy Cost (TL)	**Energy (kwh)**	**CO_2 Emissions (kg eq. CO_2)**	**Investment Cost (VAT Included) (TL)**	**Payback period for Investment (year)**
Insulation (EPS) & Roof (Rockwool)	1759.91	12029.74	2814.96	3904.81	2.22
Energy Efficient Lighting	643.54	1569.60	968.44	136.50	0.25
Energy Efficient Appliances	275.35	671.60	414.37	7546.00	27.40
PV Panels	1292.73	3153	1945.40	30428.68	23.54
Solar Panels	678.09	1653.88	1020.44	11858.87	17.49
Ground Source Heat Pump	532.10	19435.64	1191.07	66604.39	125.17
Total	5181.72	38513.45	8354.70	120479.26	23.25

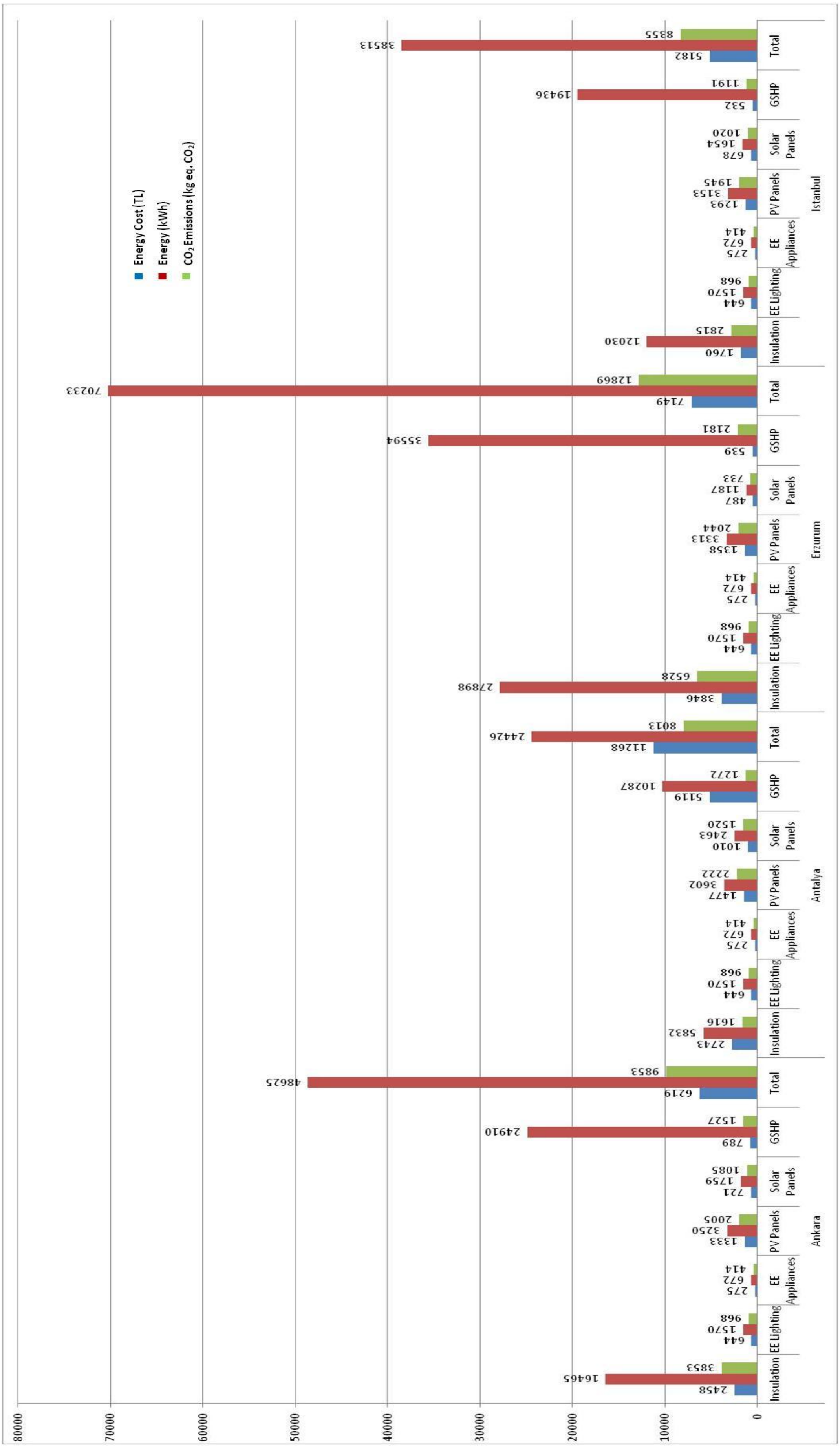


Figure 4.4. Annual saving amount of each city.

If the comparison criterion is payback period of investment cost, which means there is a limited and defined budget, then payback periods of each energy efficiency measure are sorted in ascending order for each city and energy efficiency measures with the lowest payback period can be chosen to be adopted. The sorted lists of energy efficiency measures for each city are displayed in Table 4.41-44.

Table 4.41. Payback periods of energy efficiency measures in Ankara.

Ankara		
order	**Energy Efficiency Measures**	**Payback period for Investment (year)**
1	**Energy Efficient Lighting**	0.25
2	**Insulation (EPS) & Roof (Rockwool)**	1.92
3	**Solar Panels**	16.45
4	**PV Panels**	22.84
5	**Energy Efficient Appliances**	27.40
6	**Ground Source Heat Pump**	90.13

Table 4.42. Payback periods of energy efficiency measures in Antalya.

Antalya		
order	**Energy Efficiency Measures**	**Payback period for Investment (year)**
1	**Energy Efficient Lighting**	0.25
2	**Insulation (EPS) & Roof (Rockwool)**	1.26
3	**Ground Source Heat Pump**	10.69
4	**Solar Panels**	11.74
5	**PV Panels**	20.60
6	**Energy Efficient Appliances**	27.40

Table 4.43. Payback periods of energy efficiency measures in Erzurum.

Erzurum		
order	**Energy Efficiency Measures**	**Payback period for Investment (year)**
1	**Energy Efficient Lighting**	0.25
2	**Insulation (EPS) & Roof (Rockwool)**	1.38
3	**PV Panels**	22.40
4	**Solar Panels**	24.36
5	**Energy Efficient Appliances**	27.40
6	**Ground Source Heat Pump**	131.98

Table 4.44. Payback periods of energy efficiency measures in Istanbul.

Istanbul		
order	**Energy Efficiency Measures**	**Payback period for Investment (year)**
1	**Energy Efficient Lighting**	0.25
2	**Insulation (EPS) & Roof (Rockwool)**	2.22
3	**Solar Panels**	17.49
4	**PV Panels**	23.54
5	**Energy Efficient Appliances**	27.40
6	**Ground Source Heat Pump**	125.17

Having a limited and defined budget is the most probable case most of the time and it forces decision makers to make smart investment by prioritizing among energy efficiency measures starting from the lowest payback period. By this way, a more realistic solution which is efficient, feasible and applicable at the same can be proposed. As it is shown in Table 4.41-44 energy efficient lighting and insulation are located in the first and second orders in each city and have remarkably shorter payback periods among all measures. These two measures can be adopted if the budget is very limited and the investment is urgent. As it is shown in Table 4.45; energy cost saving of 3345 TL, energy saving of 17126 kWh and carbon emission saving of 4671 kg eq. CO_2 in average can be obtained with an average investment cost of 4477 TL and an average payback period of 1.34 years is calculated. In this case the highest saving amounts are obtained in Erzurum whereas the lowest energy cost is obtained in Istanbul and the lowest energy and carbon savings are obtained in Antalya. In Ankara, energy cost saving of 3101 TL, energy saving of 18035 kWh and carbon emission saving of 4821 kg eq. CO_2 can be obtained with an investment cost of 4848 TL and a payback period of 1.56 years is calculated. In Antalya, energy cost saving of 3387 TL, energy saving of 7402 kWh and carbon emission saving of 2584 kg eq. CO_2 can be obtained with an investment cost of 3589 TL and a payback period of 1.06 years is calculated. In Erzurum, energy cost saving of 4490 TL, energy saving of 29468 kWh and carbon emission saving of 7497 kg eq. CO_2 can be obtained with an investment cost of 5428 TL and a payback period of 1.21 years is calculated. In Istanbul, energy cost saving of 2403 TL, energy saving of 13599 kWh and carbon emission saving of 3783 kg eq. CO_2 can be obtained with an investment cost of 4041 TL and a payback period of 1.68 years is calculated.

Table 4.45. Saving obtained by adopting measures with the lowest payback periods.

Insulation and Energy Efficient Lighting					
	Energy Cost (TL)	**Energy (kwh)**	**CO_2 Emissions (kg eq. CO_2)**	**Investment Cost (VAT Included) (TL)**	**Payback period for Investment (year)**
Ankara	3101.16	18035.03	4821.35	4847.91	1.56
Antalya	3386.92	7401.88	2583.99	3589.03	1.06
Erzurum	4489.59	29467.55	7496.56	5428.36	1.21
Istanbul	2403.45	13599.34	3783.40	4041.31	1.68
Average	**3345.28**	**17125.95**	**4671.33**	**4476.65**	**1.34**

However, when measures with payback periods shorter than 20 years are considered it can be concluded that; (a) insulation, energy efficient lighting and solar panels are proposed for Ankara, (b) insulation, energy efficient lighting, ground source heat pump and solar panels are proposed for Antalya, (c) insulation and energy efficient lighting are proposed for Erzurum, (d) insulation, energy efficient lighting and solar panels are proposed for Istanbul. In a nutshell, in addition to insulation and energy efficient lighting, solar panel is proposed for all cities except Erzurum and ground source heat pump is proposed for only Antalya. Despite their considerable saving amounts, PV panels and ground source heat pump are not obtained to be feasible measures since they have higher investment costs as a result of being imported technologies. As it is shown in Table 4.46-49, in case of energy efficiency measures with payback periods shorter than 20 years to be applied an investment cost of 5428 – 70148 TL in total is needed for each building in each city. With this investment cost, energy cost saving of 3082 – 9516 TL, energy saving of 15253 – 29468 kWh and carbon emission saving of 4804 – 7497 kg eq. CO_2 can be achieved in the standard building in each city. In Ankara, energy cost saving of 3822 TL, energy saving of 19794 kWh and carbon emission saving of 5907 kg eq. CO_2 can be obtained with an investment cost of 16707 TL and a payback period of 4.37 years is calculated. In Antalya, energy cost saving of 9516 TL, energy saving of 20152 kWh and carbon emission saving of 5376 kg eq. CO_2 can be obtained with an investment cost of 70148 TL and a payback period of 7.37 years is calculated. In Erzurum, energy cost saving of 4490 TL, energy saving of 29468 kWh and carbon emission saving of 7497 kg eq. CO_2 can be obtained with an investment cost of 5428 TL and a payback period of 1.21 years is calculated. Erzurum has no measures other than insulation and energy efficient lighting with payback periods shorter than 20 years hence Table 4.45 and Table 4.46 show similar results for the standard building in Erzurum. In Istanbul, energy cost saving of 3082 TL, energy saving of 15253 kWh and carbon emission saving of 4804 kg eq. CO_2 can be obtained with an investment cost of 15900 TL and a payback period of 5.16 years is calculated.

Table 4.46. Saving obtained by adopting measures with payback periods shorter than 20 years in Ankara.

Insulation, Energy Efficient Lighting and Solar Panels					
	Energy Cost (TL)	**Energy (kwh)**	**CO_2 Emissions (kg eq. CO_2)**	**Investment Cost (VAT Included) (TL)**	**Payback period for Investment (year)**
Ankara	3822.26	19793.81	5906.52	16706.78	4.37

Table 4.47. Saving obtained by adopting measures with payback periods shorter than 20 years in Antalya.

Insulation, Energy Efficient Lighting, GSHP and Solar Panels					
	Energy Cost (TL)	**Energy (kwh)**	**CO_2 Emissions (kg eq. CO_2)**	**Investment Cost (VAT Included) (TL)**	**Payback period for Investment (year)**
Antalya	9515.72	20152.02	5375.82	70148.33	7.37

Table 4.48. Saving obtained by adopting measures with payback periods shorter than 20 years in Erzurum.

Insulation and Energy Efficient Lighting					
	Energy Cost (TL)	**Energy (kwh)**	**CO_2 Emissions (kg eq. CO_2)**	**Investment Cost (VAT Included) (TL)**	**Payback period for Investment (year)**
Erzurum	4489.59	29467.55	7496.56	5428.36	1.21

Table 4.49. Saving obtained by adopting measures with payback periods shorter than 20 years in Istanbul.

Insulation, Energy Efficient Lighting and Solar Panels					
	Energy Cost (TL)	**Energy (kwh)**	**CO_2 Emissions (kg eq. CO_2)**	**Investment Cost (VAT Included) (TL)**	**Payback period for Investment (year)**
Istanbul	3081.54	15253.22	4803.85	15900.18	5.16

However, energy efficiency measures are interactive and interdependent. In order to be able to estimate savings more accurately, implementation of energy efficiency measures should be considered in concert with another. In this study, energy savings are determined and shown mainly independently and sometimes also with interaction with another as it is shown in Section 4.1 (such as PV panels with energy efficient lighting and appliances and ground source heat pump with insulation). However, summary tables which show both individual and total saving amounts stated in Section 4.2 cover independent results in order to compare each of energy efficiency measure individually and to suggest prioritization among them. Hence, total saving potentials are subject to change if all energy efficiency measures are evaluated interdependently. Nevertheless, with a rough estimation of applying all energy efficiency measures interactively, (a) total primary energy demand of 57 kWh/m^2, 33 kWh/m^2, 67 kWh/m^2, 52 kWh/m^2 per net living area can be obtained for Ankara, Antalya, Erzurum and Istanbul respectively, which are all except Erzurum below the Passive House's total primary energy demand threshold (60 kWh/m^2 per net living area) (Passive House Institute, 1996) and (b) no additional space heating energy demand can be obtained compared to the Passive House's space heating energy demand threshold (15 kWh/m^2 per net living area) (Passive House Institute, 1996).

4.2.2. Generalization of Findings to the Entire Turkey

4.2.2.1. Housing stock of Turkey. Savings, investment cost and payback periods are determined for each energy efficiency measure to be applied in the standard residential building which has two residential units and located in each four city. To be able to generalize the findings from building level to city and degree day region level, housing stock is determined since last building census in Turkey was carried out in 2000 and not revised and updated later on. Due to the lack of data about the current housing stock in Turkey, an estimation is proposed by using data of the residential building stock in 2000 and the number of construction permits granted after 2000. For this purpose total number of residential units in each city of Turkey in 2000 is obtained from Building Census 2000 and then the total number of housing construction permits between 2000 and 2015 which is announced by TUIK on quarterly basis is distributed to each city according to the ratio of housing stock in 2000. Total number of housing stock is stated in "Building Census 2000" to be 16235830 and total number of residential construction permits which is granted between 2000 and 2015 is announced to be 8817551 (Türkiye İstatistik Kurumu, 2016).

Table 4.50. Number of residential construction permits granted between 2000 and 2015.

Years	**Number of Residential Construction Permits Granted**
2001	279616
2002	161920
2003	202854
2004	330446
2005	546618
2006	600387
2007	584955
2008	503565
2009	518475
2010	907451
2011	650127
2012	771878
2013	839630
2014	1030715
2015	888914
Total	**8817551**

Since the Regulation on Building Energy Performance (BEPY) (Official Gazette 05.12.2008, no: 27075) was enacted and came into force in 2008, construction permits granted between 2000 and 2015 can be grouped into two such as the ones granted before 2008 and the ones granted after 2008. Construction permits granted before 2008 are added to the housing stock in 2000 to be able to obtain the housing stock as of 2008 which does not comply with the energy efficiency regulation. Total number of housing stock in 2008 is obtained to be 19446191 units.

Table 4.51. Housing stock in Turkey in 2000, 2008 and 2015.

Years	**Number of Residential Units**
as of 2000	16235830
as of 2008	19446191
as of 2015	25053381

It is concluded that 19 million of residential units out of 25 million residential units in other words 78% of housing stock in Turkey lack energy efficiency and present energy efficiency improvement potential.

Table 4.52. Estimation of current housing stock of Turkey.

Degree Day Regions	Province	Number of Residential Units in 2000	Ratio	Number of Residential Construction Permits (2001-2008)	Number of Residential Units in 2008	Number of Residential Construction Permits (2009-2015)	Number of Residential Units in 2015
Region 1	Adana	469189	2.89%	92774	561963	162039	724002
	Antalya	456371	2.81%	90240	546611	157612	704222
	Aydın	274260	1.69%	54230	328490	94718	423208
	Hatay	273294	1.68%	54039	327333	94385	421718
	İçel	440184	2.71%	87039	527223	152022	679244
	İzmir	1140731	7.03%	225560	1366291	393962	1760253
	Osmaniye	85733	0.53%	16952	102685	29609	132294
Region 2	Adıyaman	75690	0.47%	14966	90656	26140	116797
	Amasya	75950	0.47%	15018	90968	26230	117198
	Balıkesir	340750	2.10%	67378	408128	117681	525809
	Bursa	640197	3.94%	126588	766785	221098	987883
	Çanakkale	112877	0.70%	22320	135197	38983	174180
	Denizli	234168	1.44%	46303	280471	80872	361343
	Diyarbakır	200351	1.23%	39616	239967	69193	309160
	Edirne	94979	0.58%	18780	113759	32802	146561
	Gaziantep	279617	1.72%	55290	334907	96568	431475
	Giresun	95659	0.59%	18915	114574	33037	147611
	İstanbul	3393077	20.90%	670924	4064001	1171830	5235830
	Kocaeli	352079	2.17%	69618	421697	121594	543290
	Manisa	304817	1.88%	60272	365089	105271	470361
	Kahramanmaraş	166693	1.03%	32961	199654	57569	257223
	Mardin	87668	0.54%	17335	105003	30277	135280
	Muğla	194620	1.20%	38483	233103	67214	300317
	Ordu	163529	1.01%	32335	195864	56476	252340
	Rize	75972	0.47%	15022	90994	26238	117232
	Sakarya	156386	0.96%	30923	187309	54009	241318
	Samsun	255042	1.57%	50430	305472	88081	393553
	Siirt	30244	0.19%	5980	36224	10445	46669
	Sinop	40363	0.25%	7981	48344	13940	62284
	Tekirdağ	222641	1.37%	44023	266664	76891	343556
	Trabzon	195111	1.20%	38580	233691	67383	301074
	Şanlıurfa	158645	0.98%	31369	190014	54789	244804
	Zonguldak	142825	0.88%	28241	171066	49326	220392
	Batman	55577	0.34%	10989	66566	19194	85760
	Şırnak	38184	0.24%	7550	45734	13187	58921
	Bartın	29927	0.18%	5918	35845	10336	46180
	Yalova	80284	0.49%	15875	96159	27727	123886
	Kilis	20397	0.13%	4033	24430	7044	31474
	Düzce	37197	0.23%	7355	44552	12846	57398

Table 4.52. Estimation of current housing stock of Turkey (cont.).

Degree Day Regions	**Province**	**Number of Residential Units in 2000**	**Ratio**	**Number of Residential Construction Permits (2001-2008)**	**Number of Residential Units in 2008**	**Number of Residential Construction Permits (2009-2015)**	**Number of Residential Units in 2015**
Region 3	Afyonkarahisar	171512	1.06%	33914	205426	59233	264659
	Ankara	1128625	6.95%	223167	1351792	389781	1741572
	Artvin	30190	0.19%	5970	36160	10426	46586
	Bilecik	43671	0.27%	8635	52306	15082	67388
	Bingöl	28073	0.17%	5551	33624	9695	43319
	Bolu	48647	0.30%	9619	58266	16801	75067
	Burdur	65022	0.40%	12857	77879	22456	100335
	Çankırı	43616	0.27%	8624	52240	15063	67304
	Çorum	114547	0.71%	22650	137197	39560	176757
	Elazığ	109729	0.68%	21697	131426	37896	169322
	Eskişehir	207717	1.28%	41073	248790	71737	320526
	Isparta	122422	0.75%	24207	146629	42280	188908
	Kırklareli	83150	0.51%	16442	99592	28717	128308
	Kırşehir	55573	0.34%	10989	66562	19193	85754
	Konya	469894	2.89%	92914	562808	162282	725090
	Kütahya	154313	0.95%	30513	184826	53293	238119
	Malatya	154466	0.95%	30543	185009	53346	238355
	Nevşehir	75838	0.47%	14996	90834	26191	117025
	Niğde	79757	0.49%	15771	95528	27545	123072
	Tokat	133690	0.82%	26435	160125	46171	206296
	Tunceli	12930	0.08%	2557	15487	4465	19952
	Uşak	82656	0.51%	16344	99000	28546	127546
	Aksaray	81540	0.50%	16123	97663	28161	125824
	Karaman	55882	0.34%	11050	66932	19299	86231
	Kırıkkale	83177	0.51%	16447	99624	28726	128350
	Iğdır	20691	0.13%	4091	24782	7146	31928
	Karabük	56725	0.35%	11216	67941	19590	87532
Region 4	Ağrı	41151	0.25%	8137	49288	14212	63500
	Bitlis	36149	0.22%	7148	43297	12484	55781
	Erzincan	51796	0.32%	10242	62038	17888	79926
	Erzurum	117810	0.73%	23295	141105	40687	181792
	Gümüşhane	25977	0.16%	5137	31114	8971	40085
	Hakkari	20392	0.13%	4032	24424	7043	31467
	Kars	29557	0.18%	5844	35401	10208	45609
	Kastamonu	69899	0.43%	13821	83720	24140	107861
	Kayseri	273620	1.69%	54104	327724	94497	422221
	Muş	36019	0.22%	7122	43141	12439	55581
	Sivas	117149	0.72%	23164	140313	40458	180772
	Van	80101	0.49%	15839	95940	27664	123603
	Yozgat	111431	0.69%	22034	133465	38484	171948
	Bayburt	11369	0.07%	2248	13617	3926	17543
	Ardahan	8079	0.05%	1597	9676	2790	12467
Total		**16235830**	100.00%	**3210361**	**19446191**	**5607190**	**25053381**

To be able to generalize savings obtained in standard residential building in each city to entire four cities and degree day regions which cities are chosen as representatives from, housing stock in

2008 in each city and degree day regions are derived from Table 4.52 and stated in Table 4.53 and Table 4.54.

Table 4.53. Housing stock in four cities in 2008.

Province	**Number of Residential Units in 2008**
Antalya	546611
Istanbul	4064001
Ankara	1351792
Erzurum	141105

Table 4.54. Housing stock in four degree day regions in 2008.

Degree Day Region	**Number of Residential Units in 2008**
Region 1	3760597
Region 2	10002887
Region 3	4448444
Region 4	1234263
Total	**19446191**

4.2.2.2. Energy demand and greenhouse gas emissions of Turkey. According to International Energy Agency (IEA), Turkey’s total primary energy supply has risen considerably over the past 40 years from 24.4 million tonnes of oil-equivalent (Mtoe) in 1973 to 129.7 million tonnes of oil-equivalent (Mtoe) in 2015 and is expected to continue this trend in the coming decades (International Energy Agency, 2016b). Turkey’s total primary energy supply is expected to reach 218 million tonnes of oil-equivalent (Mtoe) in 2023 (Türkiye Cumhuriyeti Dışişleri Bakanlığı, 2017; European Commission, 2014). As being a developing country, electricity consumption of Turkey grows rapidly as well. As the Ministry of Energy and Natural Resources of Turkey announces, Turkey’s total electricity demand in 2014 was 257.2 twh and it rose by 2.7% in 2015, reaching 264.1 twh and is expected to reach at 416 twh in 2023 (International Energy Agency, 2016b, Türkiye Cumhuriyeti Enerji ve Tabii Kaynaklar Bakanlığı, 2017).

Turkey’s energy related CO_2 emissions have also been increasing similar to energy need. Turkey’s CO_2 emissions from fuel combustion were 307.1 $MtCO_2$ in 2014 which is 50% higher than in 2000 and 142% higher than in 1990 (International Energy Agency, 2016b; International Energy Agency, 2015; International Energy Agency, 2016a). The largest CO_2 emitter in Turkey is electricity and heat generation which account for 40% of all emissions (International Energy Agency, 2015; International Energy Agency, 2016a).

4.2.2.3. Energy, energy cost and carbon saving potential in Turkey. Energy, energy cost and carbon saving potentials of a standard building which consists of two residential units are calculated in Section 4.2.1 by (a) adopting measures with the shortest payback periods that is payback periods shorter than two years, (b) adopting measures with payback periods shorter than 20 years and (c) adopting all measures in order to state the whole saving potential. Total saving potentials in cities and degree day regions which standard building is located in are estimated proportioned to the number of residential units in each city and degree day region. By this way, energy and carbon saving potential of Turkey's inefficient housing stock is estimated as well.

Table 4.55. Saving potentials in cities when measures with the shortest payback periods are adopted.

Province	Number of Residential Units	Energy Cost Saving (TL)	Energy Saving (kwh)	CO_2 Emissions Saving (kg eq. CO_2)	Investment Cost (VAT Included) (TL)	Payback period for Investment (year)	Total Number of Residential Units in 2008	Energy Cost Saving (billion TL)	Energy Saving (twh)	CO_2 Emissions Saving (million tonnes eq. CO_2)	Investment Cost (VAT Included) (billion TL)
Ankara	2	3101	18035	4821	4848	1.56	1351792	2.10	12.19	3.26	3.28
Antalya	2	3387	7402	2584	3589	1.06	546611	0.93	2.02	0.71	0.98
Erzurum	2	4490	29468	7497	5428	1.21	141105	0.32	2.08	0.53	0.38
Istanbul	2	2403	13599	3783	4041	1.68	4064001	4.88	27.63	7.69	8.21

By the adoption of measures with the shortest payback periods namely payback periods shorter than two years; energy cost saving of 0.32 – 4.88 billion TL, energy saving of 2.02 – 27.63 twh and carbon emission saving of 0.53 – 7.69 million tonnes eq. CO_2 can potentially be obtained according to the size of housing stock in each four city. In Ankara in 1.35 million of residential units, energy cost saving of 2.10 billion TL, energy saving of 12.19 twh and carbon emission saving of 3.26 million tonnes eq. CO_2 can be achieved with an investment cost of 3.28 billion TL. In Antalya in 546 thousands of residential units, energy cost saving of 0.93 billion TL, energy saving of 2.02 twh and carbon emission saving of 0.71 million tonnes eq. CO_2 can be achieved with an investment cost of 0.98 billion TL. In Erzurum in 141 thousands of residential units, energy cost saving of 0.32 billion TL, energy saving of 2.08 twh and carbon emission saving of 0.53 million tonnes eq. CO_2 can be achieved with an investment cost of 0.38 billion TL. In Istanbul in 4.06 millions of residential units, energy cost saving of 4.88 billion TL, energy saving of 27.63 twh and carbon emission saving of 7.69 million tonnes eq. CO_2 can be achieved with an investment cost of 8.21 billion TL.

Table 4.56. Saving potentials in cities when measures with payback periods shorter than 20 years are adopted.

Province	Number of Residential Units	Energy Cost Saving (TL)	Energy Saving (kwh)	CO_2 Emissions Saving (kg eq. CO_2)	Investment Cost (VAT Included) (TL)	Payback period for Investment (year)	Total Number of Residential Units in 2008	Energy Cost Saving (billion TL)	Energy Saving (twh)	CO_2 Emissions Saving (million tonnes eq. CO_2)	Investment Cost (VAT Included) (billion TL)
Ankara	2	3822	19794	5907	16707	4.37	1351792	2.58	13.38	3.99	11.29
Antalya	2	9516	20152	5376	70148	7.37	546611	2.60	5.51	1.47	19.17
Erzurum	2	4490	29468	7497	5428	1.21	141105	0.32	2.08	0.53	0.38
Istanbul	2	3082	15253	4804	15900	5.16	4064001	6.26	30.99	9.76	32.31

By the adoption of measures with payback periods shorter than 20 years; energy cost saving of 0.32 – 6.26 billion TL, energy saving of 2.08 – 30.99 twh and carbon emission saving of 0.53 – 9.76 million tonnes eq. CO_2 can potentially be obtained according to the size of housing stock in each four city. In Ankara in 1.35 million of residential units, energy cost saving of 2.58 billion TL, energy saving of 13.38 twh and carbon emission saving of 3.99 million tonnes eq. CO_2 can be achieved with an investment cost of 11.29 billion TL. In Antalya in 546 thousands of residential units, energy cost saving of 2.60 billion TL, energy saving of 5.51 twh and carbon emission saving of 1.47 million tonnes eq. CO_2 can be achieved with an investment cost of 19.17 billion TL. In Erzurum in 141 thousands of residential units, energy cost saving of 0.32 billion TL, energy saving of 2.08 twh and carbon emission saving of 0.53 million tonnes eq. CO_2 can be achieved with an investment cost of 0.38 billion TL which is similar to the case of adoption of measures with the shortest payback periods namely payback periods shorter than 2 years. Erzurum has no measures with payback periods shorter than 20 years other than insulation and energy efficient lighting which have payback periods shorter than 2 years. Hence Table 4.55 and Table 4.56 show similar results for housing stock in Erzurum. In Istanbul in 4.06 millions of residential units, energy cost saving of 6.26 billion TL, energy saving of 30.99 twh and carbon emission saving of 9.76 million tonnes eq. CO_2 can be achieved with an investment cost of 32.31 billion TL.

Table 4.57. Saving potentials in cities when all measures are adopted.

Province	Number of Residential Units	Energy Cost Saving (TL)	Energy Saving (kwh)	CO_2 Emissions Saving (kg eq. CO_2)	Investment Cost (VAT Included) (TL)	Payback period for Investment (year)	Total Number of Residential Units in 2008	Energy Cost Saving (billion TL)	Energy Saving (twh)	CO_2 Emissions Saving (million tonnes eq. CO_2)	Investment Cost (VAT Included) (billion TL)
Ankara	2	6219	48625	9853	125799	20.23	1351792	4.20	32.87	6.66	85.03
Antalya	2	11268	24426	8013	108123	9.60	546611	3.08	6.68	2.19	29.55
Erzurum	2	7149	70233	12869	126379	17.68	141105	0.50	4.96	0.91	8.92
Istanbul	2	5182	38513	8355	120479	23.25	4064001	10.53	78.26	16.98	244.81

By the adoption of all measures with regardless of their payback periods; energy cost saving of 0.50 – 10.53 billion TL, energy saving of 4.96 – 78.26 twh and carbon emission saving of 0.91 – 16.98 million tonnes eq. CO_2 can potentially be obtained according to the size of housing stock in each four city. Adoption of all measures with regardless of their payback periods is important to understand saving potential notwithstanding it is evident that investing into an energy efficiency measure without neglecting the payback period is inefficient and financially infeasible. In Ankara in 1.35 million of residential units, energy cost saving of 4.20 billion TL, energy saving of 32.89 twh and carbon emission saving of 6.66 million tonnes eq. CO_2 can be achieved with an investment cost of 85.03 billion TL. In Antalya in 546 thousands of residential units, energy cost saving of 3.08 billion TL, energy saving of 6.68 twh and carbon emission saving of 2.19 million tonnes eq. CO_2 can be achieved with an investment cost of 29.55 billion TL. In Erzurum in 141 thousands of residential units, energy cost saving of 0.50 billion TL, energy saving of 4.96 twh and carbon emission saving of 0.91 million tonnes eq. CO_2 can be achieved with an investment cost of 8.92 billion TL. In Istanbul in 4.06 millions of residential units, energy cost saving of 10.53 billion TL, energy saving of 78.26 twh and carbon emission saving of 16.98 million tonnes eq. CO_2 can be achieved with an investment cost of 244.81 billion TL.

Energy, energy cost and carbon saving potentials of a representative standard building in four cities from four different degree day regions are generalized to the entire housing stock of each degree day region and by this way total saving potential of Turkey’s inefficient housing stock is estimated in Table 4.58-60.

Table 4.58. Saving potentials in degree day regions when measures with the shortest payback periods are adopted.

Degree Day Region	Number of Residential Units	Energy Cost Saving (TL)	Energy Saving (kwh)	CO_2 Emissions Saving (kg eq. CO_2)	Investment Cost (VAT Included) (TL)	Payback Period for Investment (year)	Total Number of Residential Units in 2008	Energy Cost Saving (billion TL)	Energy Saving (twh)	CO_2 Emissions Saving (million tonnes eq. CO_2)	Investment Cost (VAT Included) (billion TL)
Region 3	2	3101	18035	4821	4848	1.56	4448444	6.90	40.11	10.72	10.78
Region 1	2	3387	7402	2584	3589	1.06	3760597	6.37	13.92	4.86	6.75
Region 4	2	4490	29468	7497	5428	1.21	1234263	2.77	18.19	4.63	3.35
Region 2	2	2403	13599	3783	4041	1.68	10002887	12.02	68.02	18.92	20.21
All Regions							**19446191**	**28.06**	**140.23**	**39.13**	**41.09**

By the adoption of measures with the shortest payback periods namely payback periods shorter than two years; energy cost saving of 2.77 – 12.02 billion TL, energy saving of 13.92 – 68.02 twh and carbon emission saving of 4.63 – 18.93 million tonnes eq. CO_2 can potentially be obtained according to the size of housing stock in each degree day region. In Region 3, in 4.45 million of residential units, energy cost saving of 6.90 billion TL, energy saving of 40.11 twh and carbon emission saving of 10.72 million tonnes eq. CO_2 can be achieved with an investment cost of 10.78 billion TL. In Region 1, 3.76 million of residential units, energy cost saving of 6.37 billion TL, energy saving of 13.92 twh and carbon emission saving of 4.86 million tonnes eq. CO_2 can be achieved with an investment cost of 6.75 billion TL. In Region 4, in 1.23 million of residential units, energy cost saving of 2.77 billion TL, energy saving of 18.19 twh and carbon emission saving of 4.63 million tonnes eq. CO_2 can be achieved with an investment cost of 3.35 billion TL. In Region 2, in 1 million of residential units, energy cost saving of 12.02 billion TL, energy saving of 68.02 twh and carbon emission saving of 18.92 million tonnes eq. CO_2 can be achieved with an investment cost of 20.21 billion TL. In all regions namely in Turkey in 19.44 million of housing stock energy cost saving of 28.06 billion TL, energy saving of 140.23 twh and carbon emission saving of 39.13 million tonnes eq. CO_2 can be achieved with an investment cost of 41.09 billion TL in case of measures with the shortest payback periods are adopted. That energy saving (twh) accounts for (a) 63% of total final energy consumption of Turkish residential sector in 2014, (b) 53% and 34% of annual electrical energy demand of Turkey in 2015 and in 2023 respectively and (c) 9% and 6% of Turkey's total primary energy supply in 2015 and in 2023 respectively. That carbon emission saving accounts for (a) 13% of Turkey's total energy-related CO_2 emissions in 2014 and (b) 16% of Turkey's emission reduction target between 2020-2030 according to COP21 pledge.

Table 4.59. Saving potentials in degree day regions when measures with payback periods shorter than 20 years are adopted.

Degree Day Region	Number of Residential Units	Energy Cost Saving (TL)	Energy Saving (kwh)	CO_2 Emissions Saving (kg eq. CO_2)	Investment Cost (VAT Included) (TL)	Payback Period for Investment (year)	Total Number of Residential Units in 2008	Energy Cost Saving (billion TL)	Energy Saving (twh)	CO_2 Emissions Saving (million tonnes eq. CO_2)	Investment Cost (VAT Included) (billion TL)
Region 3	2	3822	19794	5907	16707	4.37	4448444	8.50	44.03	13.14	37.16
Region 1	2	9516	20152	5376	70148	7.37	3760597	17.89	37.89	10.11	131.90
Region 4	2	4490	29468	7497	5428	1.21	1234263	2.77	18.19	4.63	3.35
Region 2	2	3082	15253	4804	15900	5.16	10002887	15.41	76.29	24.03	79.52
All Regions							**19446191**	**44.58**	**176.39**	**51.90**	**251.93**

By the adoption of measures with payback periods shorter than 20 years; energy cost saving of 2.77 – 17.89 billion TL, energy saving of 18.19 – 76.29 twh and carbon emission saving of 4.63 – 24.03 million tonnes eq. CO_2 can potentially be obtained according to the size of housing stock in each degree day region. In Region 3, in 4.45 million of residential units, energy cost saving of 8.50 billion TL, energy saving of 44.03 twh and carbon emission saving of 13.14 million tonnes eq. CO_2 can be achieved with an investment cost of 37.16 billion TL. In Region 1, 3.76 million of residential units, energy cost saving of 17.89 billion TL, energy saving of 37.89 twh and carbon emission saving of 10.11 million tonnes eq. CO_2 can be achieved with an investment cost of 131.90 billion TL. In Region 4, in 1.23 million of residential units, energy cost saving of 2.77 billion TL, energy saving of 18.19 twh and carbon emission saving of 4.63 million tonnes eq. CO_2 can be achieved with an investment cost of 3.35 billion TL which is similar to the case of adoption of measures with the shortest payback periods namely payback periods shorter than 2 years. Region 4 has no measures with payback periods shorter than 20 years other than insulation and energy efficient lighting which have payback periods shorter than 2 years. Hence Table 4.58 and Table 4.59 show similar results for housing stock in Region 4. In Region 2, in 1 million of residential units, energy cost saving of 15.41 billion TL, energy saving of 76.29 twh and carbon emission saving of 24.03 million tonnes eq. CO_2 can be achieved with an investment cost of 79.52 billion TL. In all regions namely in Turkey in 19.44 million of housing stock energy cost saving of 44.58 billion TL, energy saving of 176.39 twh and carbon emission saving of 51.90 million tonnes eq. CO_2 can be achieved with an investment cost of 251.93 billion TL in case of measures with payback periods shorter than 20 years are adopted. That energy saving (twh) accounts for (a) 79% of total final energy consumption of Turkish residential sector in 2014, (b) 67% and 42% of annual electrical energy demand of Turkey in 2015 and in 2023 respectively and (c) 12% and 7% of Turkey’s total primary energy supply in 2015 and in 2023 respectively. That carbon emission saving accounts for (a) 17% of Turkey’s total energy-related CO_2 emissions in 2014 and (b) 21% of Turkey’s emission reduction target between 2020-2030 according to COP21 pledge.

Table 4.60. Saving potentials in degree day regions when all measures are adopted.

Degree Day Region	Number of Residential Units	Energy Cost Saving (TL)	Energy Saving (kwh)	CO_2 Emissions Saving (kg eq. CO_2)	Investment Cost (VAT Included) (TL)	Payback Period for Investment (year)	Total Number of Residential Units in 2008	Energy Cost Saving (billion TL)	Energy Saving (twh)	CO_2 Emissions Saving (million tonnes eq. CO_2)	Investment Cost (VAT Included) (billion TL)
Region 3	2	6219	48625	9853	125799	20.23	4448444	13.83	108.15	21.91	279.80
Region 1	2	11268	24426	8013	108123	9.60	3760597	21.19	45.93	15.07	203.30
Region 4	2	7149	70233	12869	126379	17.68	1234263	4.41	43.34	7.94	77.99
Region 2	2	5182	38513	8355	120479	23.25	10002887	25.92	192.62	41.79	602.57
All Regions							**19446191**	**65.35**	**390.05**	**86.71**	**1163.67**

By the adoption of all measures with regardless of their payback periods; energy cost saving of 4.41 – 25.92 billion TL, energy saving of 43.34 – 192.62 twh and carbon emission saving of 7.94 – 41.79 million tonnes eq. CO_2 can potentially be obtained according to the size of housing stock in each degree day region. In Region 3, in 4.45 million of residential units, energy cost saving of 13.83 billion TL, energy saving of 108.15 twh and carbon emission saving of 21.91 million tonnes eq. CO_2 can be achieved with an investment cost of 279.80 billion TL. In Region 1, 3.76 million of residential units, energy cost saving of 21.19 billion TL, energy saving of 45.93 twh and carbon emission saving of 15.07 million tonnes eq. CO_2 can be achieved with an investment cost of 203.30 billion TL. In Region 4, in 1.23 million of residential units, energy cost saving of 4.41 billion TL, energy saving of 43.34 twh and carbon emission saving of 7.94 million tonnes eq. CO_2 can be achieved with an investment cost of 77.99 billion TL. In Region 2, in 1 million of residential units, energy cost saving of 25.92 billion TL, energy saving of 192.62 twh and carbon emission saving of 41.79 million tonnes eq. CO_2 can be achieved with an investment cost of 602.57 billion TL. In all regions namely in Turkey in 19.44 million of housing stock energy cost saving of 65.35 billion TL, energy saving of 390.05 twh and carbon emission saving of 86.71 million tonnes eq. CO_2 can be achieved with an investment cost of 1163.67 billion TL in case of all measures are adopted. That energy saving (twh) accounts for (a) 176% of total final energy consumption of Turkish residential sector in 2014, (b) 148% and 94% of annual electrical energy demand of Turkey in 2015 and in 2023 respectively and (c) 26% and 15% of Turkey's total primary energy supply in 2015 and in 2023 respectively. That carbon emission saving accounts for (a) 28% of Turkey's total energy-related CO_2 emissions in 2014 and (b) 35% of Turkey's emission reduction target between 2020-2030 according to COP21 pledge.

Turkey's energy and carbon saving potential ratios for three adoption scenarios are summarized in Table 4.61 and in Table 4.62.

Table 4.61. Energy saving potential ratios for three adoption scenarios.

		when measures with the shortest payback periods are adopted		when measures with payback periods shorter than 20 years are adopted		when all measures are adopted	
		saving potential amount (twh)	saving potential ratio	saving potential amount (twh)	saving potential ratio	saving potential amount (twh)	saving potential ratio
Total final energy consumption of Turkish residential sector in 2014 (twh)	222	140.23	63%	176.39	79%	390.05	176%
Annual electrical energy demand of Turkey in 2015 (twh)	264	140.23	53%	176.39	67%	390.05	148%
Annual electrical energy demand of Turkey in 2023 (twh)	416	140.23	34%	176.39	42%	390.05	94%
Turkey's total primary energy supply in 2015 (twh)	1508	140.23	9%	176.39	12%	390.05	26%
Turkey's total primary energy supply in 2023 (twh)	2535	140.23	6%	176.39	7%	390.05	15%

Table 4.62. Carbon saving potential ratios for three adoption scenarios.

		when measures with the shortest payback periods are adopted		**when measures with payback periods shorter than 20 years are adopted**		**when all measures are adopted**	
		saving potential amount (million tonnes eq. CO_2)	**saving potential ratio**	**saving potential amount (million tonnes eq. CO_2)**	**saving potential ratio**	**saving potential amount (million tonnes eq. CO_2)**	**saving potential ratio**
Turkey's total energy-related CO_2 emissions in 2014 (million tonnes eq. CO_2)	307	39.13	13%	51.90	17%	86.71	28%
Turkey's emission reduction target between 2020-2030 according to COP21 pledge (million tonnes eq. CO_2)	246	39.13	16%	51.90	21%	86.71	35%

5. SUMMARY AND CONCLUSION

Greenhouse gas emissions and energy consumption levels have risen rapidly in recent decades. Building sector has provided a considerable amount of contribution to this rise. More specifically, existing buildings are responsible for a large amount of global energy consumptions and CO_2 emissions since they represent the building stock and buildings consume energy most in their operational phase. Turkey, as an emerging country, has high energy demand which mostly depends on imported energy and is one of the countries that have the highest amount of energy consumption in buildings among rest of the world. Turkey also has a huge existing building stock which is inefficient in terms of energy and does not have even any insulation. Improvement of existing building stock of Turkey in terms of energy efficiency is needed in order to achieve Turkey's national energy efficiency targets.

In the present study, possible energy efficiency measures for a standard building assumed to be located in four cities (Ankara, Antalya, Erzurum, Istanbul) from different climate regions of Turkey are analyzed and assessed in terms of technical and economic aspects with the purpose of investigating the potential for energy improvement of the existing building stock of Turkey. Available energy efficiency measures are investigated through the accessible and cost-effective technologies which can improve energy efficiency in buildings and reduce greenhouse gas emissions to a significant extent and can be realistically undertaken in Turkey. The climatic regions across Turkey are identified and the average stock building characteristics within the climatic zone characterization are determined. An energy assessment of possible improvements with energy efficiency measures is performed and building energy performance is estimated as well. Technical and economic aspects of each possible energy efficiency measure are assessed to establish the applicability of the measures. Simple payback is used as an economic analysis method. NPV is also adopted as an in-depth economic analysis tool since simple payback period method does not take into account time value of money and investment lifetime. The economic savings as well as energy and CO_2 savings of all the measures, investment costs and related payback periods are evaluated and compared with each other via the assessment of the results. According to the findings, a more feasible approach which depends on prioritization of the application of energy efficiency measures can be suggested for the buildings with different characteristics in different climates in terms of both technical and economical applicability and efficiency. Energy, carbon and cost savings potentials in each climate region and city which is chosen as the representative of region in this study are stated and total saving potential of Turkey's building stock is estimated. The approach proposed in this study can help decision makers to plan and evaluate their energy efficiency retrofitting strategies by guiding them to select appropriate energy efficiency measures to achieve maximum environmental and economic benefits.

Ideas emerged from this study are discussed as below:

Thermal insulation is more effective in terms of savings in colder areas. Largest energy saving in kWh and CO_2 emission reduction are obtained in Erzurum which is the coldest city among four cities while smallest energy and CO_2 saving are obtained in Antalya as being the warmest city. Thermal insulation has shorter payback periods in colder areas in general. However, fuel price has a direct effect on payback period. Hence, thermal insulation can be economically more effective in areas with more expensive fuel prices. Payback period of investment is relatively shorter in Antalya and Erzurum since insulation provides great saving amounts in terms of kWh and TL in Erzurum which is the coldest city and thus has the largest saving potential and insulation provides second highest saving amount in TL in Antalya because of higher price of fuel. Thermal insulation can achieve energy cost saving of 2458 TL/year, energy saving of 16465 kWh/year and carbon saving of 3853 kg eq. CO_2/year with an investment cost of 4711 TL and payback period of 1.92 years in the standard building in Ankara. Thermal insulation can achieve energy cost saving of 2743 TL/year, energy saving of 5832 kWh/year and carbon saving of 1616 kg eq. CO_2/year with an investment cost of 3453 TL and payback period of 1.26 years in the standard building in Antalya. Thermal insulation can achieve energy cost saving of 3846 TL/year, energy saving of 27898 kWh/year and carbon saving of 6528 kg eq. CO_2/year with an investment cost of 5292 TL and payback period of 1.38 years in the standard building in Erzurum. Thermal insulation can achieve energy cost saving of 1760 TL/year, energy saving of 12030 kWh/year and carbon saving of 2815 kg eq. CO_2/year with an investment cost of 3905 TL and payback period of 2.22 years in the standard building in Istanbul.

Energy and CO_2 emission savings as a result of energy efficient lighting and appliances are all at the same amount in four cities since these improvements does not depend on degree days and location. Payback period of changing incandescent lamps with compact fluorescent and led lamps can be shorter than one year (~three months) whereas upgrading appliances with efficient ones can be about 30 years (27.40 years). This is because the cost of energy consumption difference between Class A (efficient) and Class B (inefficient) appliances is not sufficient to compensate the investment cost of Class A appliances in a shorter time period. Moreover, there is only 7% saving difference between energy performance of Class A and Class B appliances which makes upgrading from Class B to Class A appliances not to be that much feasible. Energy efficient lighting can achieve energy cost saving of 644 TL/year, energy saving of 1570 kWh/year and carbon saving of 968 kg eq. CO_2/year with an investment cost of 137 TL and payback period of 0.25 years in the standard building in each city. Energy efficient appliances can achieve energy cost saving of 275 TL/year, energy saving of 672 kWh/year and carbon saving of 414 kg eq. CO_2/year with an investment cost of 7546 TL and payback period of 27.40 years in the standard building in each city.

Largest amount of electricity production from photovoltaic panels and therefore largest amount of energy and CO_2 savings are obtained in Antalya which is the city from the first degree day region. However saving amounts in all four cities are very close to each other and Antalya is followed by Erzurum, Ankara and Istanbul respectively. Photovoltaic panels result in 30% saving whereas payback periods are about 20 years because of high investment costs which depends on foreign currency. Photovoltaic panels can achieve energy cost saving of 1333 TL/year, energy saving of 3250 kWh/year and carbon saving of 2005 kg eq. CO_2/year with an investment cost of 30429 TL and payback period of 22.84 years in the standard building in Ankara. Photovoltaic panels can achieve energy cost saving of 1477 TL/year, energy saving of 3602 kWh/year and carbon saving of 2222 kg eq. CO_2/year with an investment cost of 30429 TL and payback period of 20.60 years in the standard building in Antalya. Photovoltaic panels can achieve energy cost saving of 1358 TL/year, energy saving of 3313 kWh/year and carbon saving of 2044 kg eq. CO_2/year with an investment cost of 30429 TL and payback period of 22.40 years in the standard building in Erzurum. Photovoltaic panels can achieve energy cost saving of 1293 TL/year, energy saving of 3153 kWh/year and carbon saving of 1945 kg eq. CO_2/year with an investment cost of 30429 TL and payback period of 23.54 years in the standard building in Istanbul.

By using solar panels, remarkable emissions reduction and energy saving can be achievable for all degree day regions. Maximum saving and the shortest payback period are observed in Antalya since it is in the first degree day region hence it is easier to heat water by its gained solar energy. However, minimum saving and the longest payback period are observed in Erzurum since it is in the fourth degree day region hence it is more difficult to heat water by its gained solar energy. Solar panels can achieve energy cost saving of 721 TL/year, energy saving of 1759 kWh/year and carbon saving of 1085 kg eq. CO_2/year with an investment cost of 11859 TL and payback period of 16.45 years in the standard building in Ankara. Solar panels can achieve energy cost saving of 1010 TL/year, energy saving of 2463 kWh/year and carbon saving of 1520 kg eq. CO_2/year with an investment cost of 11859 TL and payback period of 11.74 years in the standard building in Antalya. Solar panels can achieve energy cost saving of 487 TL/year, energy saving of 1187 kWh/year and carbon saving of 733 kg eq. CO_2/year with an investment cost of 11859 TL and payback period of 24.36 years in the standard building in Erzurum. Solar panels can achieve energy cost saving of 678 TL/year, energy saving of 1654 kWh/year and carbon saving of 1020 kg eq. CO_2/year with an investment cost of 11859 TL and payback period of 17.49 years in the standard building in Istanbul.

Since a ground source heat pump with smaller capacity and shorter drilling length would be used in Antalya, the smallest investment cost and energy need for heating is calculated in Antalya. Accordingly, the largest investment cost as well as the largest cost of electrical energy consumption by heat pump is calculated in Erzurum. GSHP can achieve energy cost saving of 789 TL/year, energy saving of 31288 kWh/year and carbon saving of 3019 kg eq. CO_2/year with an investment cost of 71117 TL and payback period of 90.13 years in the standard building in Ankara. GSHP can achieve energy cost saving of 5119 TL/year, energy saving of 11585 kWh/year and carbon saving of 1632 kg eq. CO_2/year with an investment cost of 54700 TL and payback period of 10.69 years in the standard building in Antalya. GSHP can achieve energy cost saving of 539 TL/year, energy saving of 44708 kWh/year and carbon saving of 4314 kg eq. CO_2/year with an investment cost of 71117 TL and payback period of 131.98 years in the standard building in Erzurum. GSHP can achieve energy cost saving of 532 TL/year, energy saving of 24412 kWh/year and carbon saving of 2356 kg eq. CO_2/year with an investment cost of 66604 TL and payback period of 125.17 years in the standard building in Istanbul. GSHP can be economically more efficient in terms of annual saving (TL) and payback period in colder areas and in areas with more expensive fuel prices. However, since the investment cost of heat pump is significantly high, it seems not be affordable to adopt this technology.

When energy efficiency measures in all four cities are compared with each other in terms of savings, investment costs, payback periods and NPV, it is concluded that:

- Insulation has the largest potential in terms of energy cost and carbon emissions savings, and ground source heat pump has the largest potential in terms of energy saving while PV panels has the third largest potential in terms of energy cost and energy and the second largest potential in terms of carbon emissions.
- Insulation and ground source heat pump measures save considerable amount of energy (kWh) while energy efficient appliances save moderate amount of energy.
- PV panels and insulation measures achieve higher amount of carbon emission reduction, whereas energy efficient lighting and appliances result in lower amount of emission reduction.

- Insulation and PV panels result in higher energy cost (TL) saving amounts. However, ground source heat pump measure achieves highest energy cost saving amount in Antalya unlike other measures.
- Energy efficient lighting achieves the highest saving ratio (71%) among all measures while energy efficient appliances result in the lowest saving ratio (7%). Ground source heat pump measure achieves highest energy cost saving ratio (73%) in Antalya as well. Ground source heat pump measure also results in very high saving ratio (69%) in other three cities.
- Although energy, energy cost and carbon emission savings of lighting are not that much high compared to that of other measures, in addition to its highest saving ratio it has the lowest investment cost and shortest payback period (0.25 years) among all the measures which makes it the most cost efficient and applicable measure in terms of technical and economic feasibility.
- Insulation has also shorter payback period (1.26-2.22 years) compared to other measures while ground source heat pump has highest investment cost and longest payback period (around 100 years).
- In Antalya, despite the high investment cost ground source heat pump performs better and results in considerable amount of energy cost saving and a shorter payback period (10.69 years).
- PV panels save more energy, energy cost and carbon than solar panels do, however they need higher investment cost and have longer payback period compared to solar panels which makes them less feasible than solar panels. Except the case in Erzurum, most of the time solar panels have payback periods shorter than 20 years. On the other hand, payback periods of PV panels are around 20 years that makes this measure arguable in terms of financial feasibility.
- Only insulation (11532 TL-28150 TL) and lighting (5391 TL) have positive NPV whereas all other measures have negative NPV in all cities. Despite the shortest payback period of lighting, the largest NPV is obtained by insulation in all cities. NPV of insulation is the largest in Erzurum (28150 TL) and Erzurum is followed by Antalya (20372 TL), Ankara (16779 TL) and Istanbul (11532 TL), respectively.
- PV panels and ground source heat pumps require higher investment costs since they require imported technology and the investment depends on foreign currency, hence despite their remarkable saving amounts these measures are obtained to be infeasible.
- Insulation is the energy efficiency measure which has the highest energy cost saving potential in Ankara, Erzurum and Istanbul while ground source heat pump is the measure

that has the highest energy cost saving potential in Antalya. Solar panels and PV panels achieve shortest payback period in Antalya.

- Implementing insulation to an non-insulated building before installing heat pump would be a more efficient option since it requires lower investment cost and results in considerable amount of saving and shorter payback period.
- Heat pump causes about 30% less emissions and 70% less energy consumption than that of stove causes in all cities.
- If all energy efficiency measures are implemented together highest energy (kWh) and carbon emission savings potential are obtained in Erzurum while highest energy cost (TL) saving potential is obtained in Antalya.

Comparison criterion among energy efficiency measures can be savings (energy, energy cost and carbon) if a budget is not considered and environmental benefits are prioritized. However, the criterion can be payback period of investment cost if there is a limited and defined budget and financial benefits are prioritized. The former case results in adopting all energy efficiency measures or selection among them with the highest saving amount of targeted saving type such as energy and carbon. The latter case force decision maker of investment to make prioritization among energy efficiency measures starting from the lowest payback period. Therefore if a budget is defined, which is the case most of the time, the most feasible energy efficiency measures are expected to be adopted.

If comparison criterion is savings (energy, energy cost or carbon), energy efficiency measures with the highest saving potential are obtained by sorting the savings of each energy efficiency measure in descending order for each city. The ones with highest savings that will meet saving goals can be chosen to be adopted if a budget is not considered. In order to obtain maximum amount of savings, all energy efficiency measures can be adopted. In case of all energy efficiency measures to be applied: (a) In the standard building in Ankara, energy cost saving of 6219 TL/year, energy saving of 48625 kWh/year and carbon emission saving of 9853 kg eq. CO_2/year can be obtained with an investment cost of 125799 TL and a payback period of 20.2 years is calculated; (b) In the standard building in Antalya, energy cost saving of 11268 TL/year, energy saving of 24426 kWh/year and carbon emission saving of 8013 kg eq. CO_2/year can be obtained with an investment cost of 108123 TL and a payback period of 9.6 years is calculated; (c) In the standard building in Erzurum, energy cost saving of 7149 TL/year, energy saving of 70233 kWh/year and carbon emission saving of 12869 kg eq. CO_2/year can be obtained with an investment cost of 126379 TL and a payback period of 17.7 years is calculated; (d) In the standard building in Istanbul, energy cost saving of 5182 TL/year, energy saving of 38513 kWh/year and carbon emission saving of 8355 kg eq. CO_2/year can be obtained with an investment cost of 120479 TL and a payback period of 23.3 years is calculated.

If the comparison criterion is payback period of investment cost, which means there is a limited and defined budget, then payback periods of each energy efficiency measure are sorted in ascending order for each city and energy efficiency measures with the lowest payback period can be chosen to be adopted. Having a limited and defined budget is the most probable case most of the time and it forces decision makers to make smart investment by prioritizing among energy efficiency measures starting from the lowest payback period. By this way, a more realistic solution which is efficient, feasible and applicable at the same can be proposed. Energy efficient lighting and insulation are located in the first and second orders in each city and have remarkably shorter payback periods among all measures. These two measures can be adopted if the budget is very limited and the investment is urgent. In this case the highest saving amounts are obtained in Erzurum whereas the lowest energy cost is obtained in Istanbul and the lowest energy and carbon savings are obtained in Antalya. In case of energy efficiency measures with the lowest payback periods to be applied: (a) In the standard building in Ankara, energy cost saving of 3101 TL/year, energy saving of 18035 kWh/year and carbon emission saving of 4821 kg eq. CO_2/year can be obtained with an investment cost of 4848 TL and a payback period of 1.56 years is calculated; (b) In the standard building in Antalya, energy cost saving of 3387 TL/year, energy saving of 7402 kWh/year and carbon emission saving of 2584 kg eq. CO_2/year can be obtained with an investment cost of 3589 TL and a payback period of 1.06 years is calculated; (c) In the standard building in Erzurum, energy cost saving of 4490 TL/year, energy saving of 29468 kWh/year and carbon emission saving of 7497 kg eq. CO_2/year can be obtained with an investment cost of 5428 TL and a payback period of 1.21 years is calculated; (d) In the standard building in Istanbul, energy cost saving of 2403 TL/year, energy saving of 13599 kWh/year and carbon emission saving of 3783 kg eq. CO_2/year can be obtained with an investment cost of 4041 TL and a payback period of 1.68 years is calculated.

However, when measures with payback periods shorter than 20 years are considered it can be concluded that; (a) insulation, energy efficient lighting and solar panels are proposed for Ankara, (b) insulation, energy efficient lighting, ground source heat pump and solar panels are proposed for Antalya, (c) insulation and energy efficient lighting are proposed for Erzurum, (d) insulation, energy efficient lighting and solar panels are proposed for Istanbul. In other words, in addition to insulation and energy efficient lighting, solar panel is proposed for all cities except Erzurum and ground source heat pump is proposed for only Antalya. In case of energy efficiency measures with payback periods shorter than 20 years to be applied: (a) In the standard building in Ankara, energy cost saving of 3822 TL/year, energy saving of 19794 kWh/year and carbon emission saving of 5907 kg eq. CO_2/year can be obtained with an investment cost of 16707 TL and a payback period of 4.37 years is calculated; (b) In the standard building in Antalya, energy cost saving of 9516 TL/year, energy saving of 20152 kWh/year and carbon emission saving of 5376 kg eq. CO_2/year can be obtained with an investment cost of 70148 TL and a payback period of 7.37 years is calculated; (c) In the standard building in Erzurum, energy cost saving of 4490 TL/year, energy saving of 29468 kWh/year and carbon emission saving of 7497 kg eq. CO_2/year can be obtained with an investment cost of 5428 TL and a payback period of 1.21 years is calculated; (d) In the standard building in Istanbul, energy cost saving of 3082 TL/year, energy saving of 15253 kWh/year and carbon emission saving of 4804 kg eq. CO_2/year can be obtained with an investment cost of 15900 TL and a payback period of 5.16 years is calculated.

To be able to generalize the findings from building level to city and degree day region level, housing stock is estimated by using data of the residential building stock in 2000 and the number of construction permits granted after 2000. Since the Regulation on Building Energy Performance was enacted and came into force in 2008, construction permits granted before 2008 are added to the housing stock in 2000 to be able to obtain the housing stock as of 2008 which does not comply with the energy efficiency regulation. It is concluded that 19 million of residential units out of 25 million residential units in other words 78% of housing stock in Turkey lack energy efficiency and present energy efficiency improvement potential. Total saving potentials in cities and degree day regions which standard building is located in are estimated proportioned to the number of residential units in each city and degree day region. By this way, energy and carbon saving potential of Turkey’s inefficient housing stock is estimated as well.

In case of measures with the shortest payback periods namely payback periods shorter than two years are adopted in 19.44 million of housing stock in Turkey; energy cost saving of 28.06 billion TL/year, energy saving of 140.23 twh/year and carbon emission saving of 39.13 million tonnes eq. CO_2/year can be achieved with an investment cost of 41.09 billion TL in case of measures with the shortest payback periods are adopted. That energy saving (twh) accounts for (a) 63% of total final energy consumption of Turkish residential sector in 2014, (b) 53% and 34% of annual electrical energy demand of Turkey in 2015 and in 2023 respectively and (c) 9% and 6% of Turkey’s total primary energy supply in 2015 and in 2023 respectively. That carbon emission saving accounts for

(a) 13% of Turkey’s total energy-related CO_2 emissions in 2014 and (b) 16% of Turkey’s emission reduction target between 2020-2030 according to COP21 pledge.

In case of measures with payback periods shorter than 20 years are adopted in 19.44 million of housing stock in Turkey; energy cost saving of 44.58 billion TL/year, energy saving of 176.39 twh/year and carbon emission saving of 51.90 million tonnes eq. CO_2/year can be achieved with an investment cost of 251.93 billion TL in case of measures with payback periods shorter than 20 years are adopted. That energy saving (twh) accounts for (a) 79% of total final energy consumption of Turkish residential sector in 2014, (b) 67% and 42% of annual electrical energy demand of Turkey in 2015 and in 2023 respectively and (c) 12% and 7% of Turkey’s total primary energy supply in 2015 and in 2023 respectively. That carbon emission saving accounts for (a) 17% of Turkey’s total energy-related CO_2 emissions in 2014 and (b) 21% of Turkey’s emission reduction target between 2020-2030 according to COP21 pledge.

In case of all measures with regardless of their payback periods are adopted to understand whole saving potential in 19.44 million of housing stock in Turkey; energy cost saving of 65.35 billion TL/year, energy saving of 390.05 twh/year and carbon emission saving of 86.71 million tonnes eq. CO_2/year can be achieved with an investment cost of 1163.67 billion TL. That energy saving (twh) accounts for (a) 176% of total final energy consumption of Turkish residential sector in 2014, (b) 148% and 94% of annual electrical energy demand of Turkey in 2015 and in 2023 respectively and (c) 26% and 15% of Turkey’s total primary energy supply in 2015 and in 2023 respectively. That carbon emission saving accounts for (a) 28% of Turkey’s total energy-related CO_2 emissions in 2014 and (b) 35% of Turkey’s emission reduction target between 2020-2030 according to COP21 pledge.

Lessons learnt from this study in a broader aspect and suggestions that can be made according to findings of the present study are discussed as below:

A considerable amount of energy saving and emission reduction can be achievable with energy efficiency retrofitting of existing buildings. Maximizing energy savings, cost savings and reduction in CO_2 emissions are all interrelated with each other. Energy consumption directly results in cost savings and CO_2 emissions reductions or the other way around. In addition to energy saving, investing in any energy efficiency measure results in both cost saving and CO_2 emissions saving. However, selecting the energy efficiency measures does not only depend on available technologies but also budget constraints. Therefore, in order to implement energy efficiency measures both technical and economic assessment should be taken into account.

Although the same level of energy saving can be obtained, energy cost savings and CO_2 emission savings can be different. There can be a trade-off between maximizing cost savings, energy savings, CO_2 emissions savings and minimizing investment costs. It can be dealt with prioritization of energy efficiency measures and optimization of savings and budget.

Energy saving focused retrofitting measures usually require lower amount of investment costs compared to renewable technologies. Hence they are more affordable and adoptable at the same time. Renewable energy is not necessarily the best and the most feasible option for energy efficiency retrofitting especially for huge building stocks. Renewable technologies have gained noticeable growth in past decade. However, there are still ongoing debates especially on cost and ecological effects. These technologies also may not be affordable because of high currencies and being imported technologies.

Given that there are nearly 20 million residential units in Turkey and most of them do not comply with energy efficiency standards, implementing energy efficiency measures in this building stock offers great benefits in terms of national energy targets.

According to the statements made by the Ministry of Environment and Urbanization in Turkey, with the national urban regeneration movement, 6.7 millions of houses are targeted to be demolished and reconstructed until 2030. In other words, approximately 334000 houses will be demolished and reconstructed every year, which will require a resource of 465 billion USD in total in 20 years (Çamlıbel et al., 2015). Projects for renewal of existing houses should be actively encouraged during the urban regeneration process. Constructing new energy efficient buildings and renewal of existing ones in terms of energy efficiency within the scope of urban regeneration offers significant opportunities. This can help to transform the building stock in terms of energy efficiency and contribute to national energy efficiency target which is to make at least one fourth of the building stock in 2010 sustainable by 2023. And also energy that can be saved in existing buildings can decrease national energy demand in future.

Subsidies can be provided for energy efficiency retrofitting of buildings. Renewable technologies can be encouraged through allowing excess amount of electricity generated from them to be fed into the grid. Similarly, taxation benefits can be applied to the existing buildings that meet minimum energy requirements. Energy retrofitting of existing buildings can be funded with a tax relief, or some government incentives can be given according to the economically viable ones. Government grants, subsidies and tax incentives for homeowners to implement energy efficiency measures can be provided.

In addition to energy efficiency measures, building management and operation is also crucial to maintain the effectiveness of building retrofit as well as building occupier’s behavior which directly affects the energy performance of the building. In this regard, energy service companies and energy performance contracts can be used as an important tool for energy efficiency retrofitting of existing buildings.

The approach stated in this study can be more effective by including interaction of energy efficiency measures, effects of occupant behavior and optimal selection through a group of energy efficiency measures which can be considered in future research. Further investigations can be carried out in order to develop decision-making models to select the optimum energy efficient building retrofitting strategy in order to maximize environmental and financial savings. The findings of the present study can contribute to decision makers to develop energy retrofitting strategies and policies, business and financial models, business plans for retrofitting for both building level and housing stock level projects.

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APPENDIX A: THERMAL INSULATION CALCULATIONS

Thermal insulation thickness and related insulation cost calculations are shown in Table A.1-4.

Table A.1. Insulation thickness and cost in Ankara.

	Building Parts	**Net Insulation Surface Area (m²)**	**Ankara**		
			Insulation Thickness (cm)	**Unit cost of Insulation (TL/m²)**	**Cost of Insulation (TL)**
XPS (except roof)	External Façade	264.92	8	19.3	5113.0
	Roof (Rockwool)	108.58	10	6.26	680.0
	Slab (Ground Floor)-*Carpet surface*	61.79	3	24.80	1532.2
	Slab (Ground Floor)-*Ceramic surface*	20.81	3	31.30	651.3
	Slab (First Floor)-*Carpet surface*	61.79	2	23.29	1438.8
	Slab (First Floor)-*Ceramic surface*	20.81	2	29.79	619.8
	TOTAL (VAT excluded)				**10035.1**
EPS (except roof)	External Façade	273.78	8	12.1	3312.7
	Roof (Rockwool)	108.58	10	6.26	680.0
	Slab (Ground Floor)-*Carpet surface*	61.79	3	24.80	1532.2
	Slab (Ground Floor)-*Ceramic surface*	20.81	3	31.30	651.3
	Slab (First Floor)-*Carpet surface*	61.79	2	23.29	1438.8
	Slab (First Floor)-*Ceramic surface*	20.81	2	29.79	619.8
	TOTAL (VAT excluded)				**8234.9**

Table A.2. Insulation thickness and cost in Antalya.

	Building Parts	**Net Insulation Surface Area (m²)**	**Antalya**		
			Insulation Thickness (cm)	**Unit cost of Insulation (TL/m²)**	**Cost of Insulation (TL)**
XPS (except roof)	External Façade	264.92	3	11.4	3020.1
	Roof (Rockwool)	108.58	8	5.01	544.0
	Slab (Ground Floor)-*Carpet surface*	61.79	3	24.80	1532.2
	Slab (Ground Floor)-*Ceramic surface*	20.81	3	31.30	651.3
	Slab (First Floor)-*Carpet surface*	61.79	2	23.29	1438.8
	Slab (First Floor)-*Ceramic surface*	20.81	2	29.79	619.8
	TOTAL (VAT excluded)				**7806.2**
EPS (except roof)	External Façade	273.78	3	8.7	2381.9
	Roof (Rockwool)	108.58	8	5.01	544.0
	Slab (Ground Floor)-*Carpet surface*	61.79	3	24.80	1532.2
	Slab (Ground Floor)-*Ceramic surface*	20.81	3	31.30	651.3
	Slab (First Floor)-*Carpet surface*	61.79	2	23.29	1438.8
	Slab (First Floor)-*Ceramic surface*	20.81	2	29.79	619.8
	TOTAL (VAT excluded)				**7168.0**

Table A.3. Insulation thickness and cost in Erzurum.

	Building Parts	**Net Insulation Surface Area (m^2)**	**Erzurum**		
			Insulation Thickness (cm)	**Unit cost of Insulation (TL/m^2)**	**Cost of Insulation (TL)**
XPS (except roof)	External Façade	264.92	10	22.5	5960.7
	Roof (Rockwool)	108.58	12	7.52	816.0
	Slab (Ground Floor)-*Carpet surface*	61.79	3	24.80	1532.2
	Slab (Ground Floor)-*Ceramic surface*	20.81	3	31.30	651.3
	Slab (First Floor)-*Carpet surface*	61.79	2	23.29	1438.8
	Slab (First Floor)-*Ceramic surface*	20.81	2	29.79	619.8
	TOTAL (VAT excluded)				**11018.8**
EPS (except roof)	External Façade	273.78	10	13.4	3668.7
	Roof (Rockwool)	108.58	12	7.52	816.0
	Slab (Ground Floor)-*Carpet surface*	61.79	3	24.80	1532.2
	Slab (Ground Floor)-*Ceramic surface*	20.81	3	31.30	651.3
	Slab (First Floor)-*Carpet surface*	61.79	2	23.29	1438.8
	Slab (First Floor)-*Ceramic surface*	20.81	2	29.79	619.8
	TOTAL (VAT excluded)				**8726.8**

Table A.4. Insulation thickness and cost in Istanbul.

	Building Parts	**Net Insulation Surface Area (m^2)**	**Istanbul**		
			Insulation Thickness (cm)	**Unit cost of Insulation (TL/m^2)**	**Cost of Insulation (TL)**
XPS (except roof)	External Façade	264.92	5	14.7	3894.3
	Roof (Rockwool)	108.58	8	5.01	544.0
	Slab (Ground Floor)-*Carpet surface*	61.79	3	24.80	1532.2
	Slab (Ground Floor)-*Ceramic surface*	20.81	3	31.30	651.3
	Slab (First Floor)-*Carpet surface*	61.79	2	23.29	1438.8
	Slab (First Floor)-*Ceramic surface*	20.81	2	29.79	619.8
	TOTAL (VAT excluded)				**8680.5**
EPS (except roof)	External Façade	273.78	5	10.1	2765.2
	Roof (Rockwool)	108.58	8	5.01	544.0
	Slab (Ground Floor)-*Carpet surface*	61.79	3	24.80	1532.2
	Slab (Ground Floor)-*Ceramic surface*	20.81	3	31.30	651.3
	Slab (First Floor)-*Carpet surface*	61.79	2	23.29	1438.8
	Slab (First Floor)-*Ceramic surface*	20.81	2	29.79	619.8
	TOTAL (VAT excluded)				**7551.3**

Table A.5-9 shows heat loses for both insulated and non-insulated cases in four cities in detail.

Table A.5. Heat losses for both insulated and non-insulated cases in four cities

	Heat Loss (Watt)		**Heat Loss Difference (Watt)**
	Non-insulated	**Insulated**	
Ankara	38054	20718	17336
Antalya	23658	14414	9244
Erzurum	45468	20907	24561
Istanbul	29155	16718	12437

Table A.6. Heat losses for both insulated and non-insulated cases in Ankara.

Building Part Code	**Building Part**	**Area (m^2)**	**ANKARA**			
			Outdoor Temperature (^oC)	**Indoor Temperature (^oC)**	**Non-insulated Heat Loss (Watt)**	**Insulated Heat Loss (Watt)**
GF01	hall-like room (sofa)	25.65	-12.R	22	3005	2138
GF02	guests' room	13.00	-12.R	22	3300	2322
GF03	bedroom	10.54	-12.R	20	2162	1364
GF04	parents' bedroom	12.60	-12.R	20	2439	1556
GF05	WC	1.56	-12.R	18	410	271
GF06	hall	2.73	-12.R	18	124	66
GF07	bathroom	4.76	-12.R	26	1714	964
Gf08	kitchen	11.76	-12.R	18	2513	1616
1F01	hall-like room (sofa)	25.65	-12.R	22	5079	1982
1F02	guests' room	13.00	-12.R	22	4306	2247
1F03	bedroom	10.54	-12.R	20	2965	1319
1F04	parents' bedroom	12.60	-12.R	20	3487	1498
1F05	WC	1.56	-12.R	18	533	268
1F06	hall	2.73	-12.R	18	385	106
1F07	bathroom	4.76	-12.R	26	2156	916
1F08	kitchen	11.76	-12.R	18	3476	2085

Table A.7. Heat losses for both insulated and non-insulated cases in Antalya.

Building Part Code	Building Part	Area (m^2)	ANTALYA			
			Outdoor Temperature (^{o}C)	Indoor Temperature (^{o}C)	Non-insulated Heat Loss (Watt)	Insulated Heat Loss (Watt)
GF01	hall-like room (sofa)	25.65	3.R	22	2115	1296
GF02	guests' room	13.00	3.R	22	2426	1813
GF03	bedroom	10.54	3.R	20	1436	975
GF04	parents' bedroom	12.60	3.R	20	1645	1101
GF05	WC	1.56	3.R	18	285	215
GF06	hall	2.73	3.R	18	100	41
GF07	bathroom	4.76	3.R	26	1280	834
Gf08	kitchen	11.76	3.R	18	1635	1152
1F01	hall-like room (sofa)	25.65	3.R	22	2697	1141
1F02	guests' room	13.00	3.R	22	2708	1737
1F03	bedroom	10.54	3.R	20	1653	930
1F04	parents' bedroom	12.60	3.R	20	1928	1042
1F05	WC	1.56	3.R	18	304	198
1F06	hall	2.73	3.R	18	156	35
1F07	bathroom	4.76	3.R	26	1404	787
1F08	kitchen	11.76	3.R	18	1886	1117

Table A.8. Heat losses for both insulated and non-insulated cases in Erzurum.

Building Part Code	Building Part	Area (m^2)	ERZURUM			
			Outdoor Temperature (^{o}C)	Indoor Temperature (^{o}C)	Non-insulated Heat Loss (Watt)	Insulated Heat Loss (Watt)
GF01	hall-like room (sofa)	25.65	-21.N	22	3753	2362
GF02	guests' room	13.00	-21.N	22	3680	2260
GF03	bedroom	10.54	-21.N	20	2593	1415
GF04	parents' bedroom	12.60	-21.N	20	2924	1602
GF05	WC	1.56	-21.N	18	477	270
GF06	hall	2.73	-21.N	18	245	137
GF07	bathroom	4.76	-21.N	26	2032	972
Gf08	kitchen	11.76	-21.N	18	2990	1633
1F01	hall-like room (sofa)	25.65	-21.N	22	6272	2213
1F02	guests' room	13.00	-21.N	22	4900	2187
1F03	bedroom	10.54	-21.N	20	3571	1368
1F04	parents' bedroom	12.60	-21.N	20	4200	1543
1F05	WC	1.56	-21.N	18	625	264
1F06	hall	2.73	-21.N	18	507	129
1F07	bathroom	4.76	-21.N	26	2531	932
1F08	kitchen	11.76	-21.N	18	4168	1620

Table A.9. Heat losses for both insulated and non-insulated cases in Istanbul.

Building Part Code	**Building Part**	**Area (m^2)**	**ISTANBUL**			
			Outdoor Temperature (°C)	**Indoor Temperature (°C)**	**Non-insulated Heat Loss (Watt)**	**Insulated Heat Loss (Watt)**
GF01	hall-like room (sofa)	25.65	-3.R	22	2416	1637
GF02	guests' room	13.00	-3.R	22	2755	2022
GF03	bedroom	10.54	-3.R	20	1709	1133
GF04	parents' bedroom	12.60	-3.R	20	1939	1286
GF05	WC	1.56	-3.R	18	324	230
GF06	hall	2.73	-3.R	18	124	70
GF07	bathroom	4.76	-3.R	26	1456	888
Gf08	kitchen	11.76	-3.R	18	1965	1339
1F01	hall-like room (sofa)	25.65	-3.R	22	3603	1457
1F02	guests' room	13.00	-3.R	22	3330	1934
1F03	bedroom	10.54	-3.R	20	2164	1082
1F04	parents' bedroom	12.60	-3.R	20	2532	1219
1F05	WC	1.56	-3.R	18	393	225
1F06	hall	2.73	-3.R	18	244	61
1F07	bathroom	4.76	-3.R	26	1697	834
1F08	kitchen	11.76	-3.R	18	2504	1301

Table A.10 shows heating costs for both insulated and non-insulated cases in four cities.

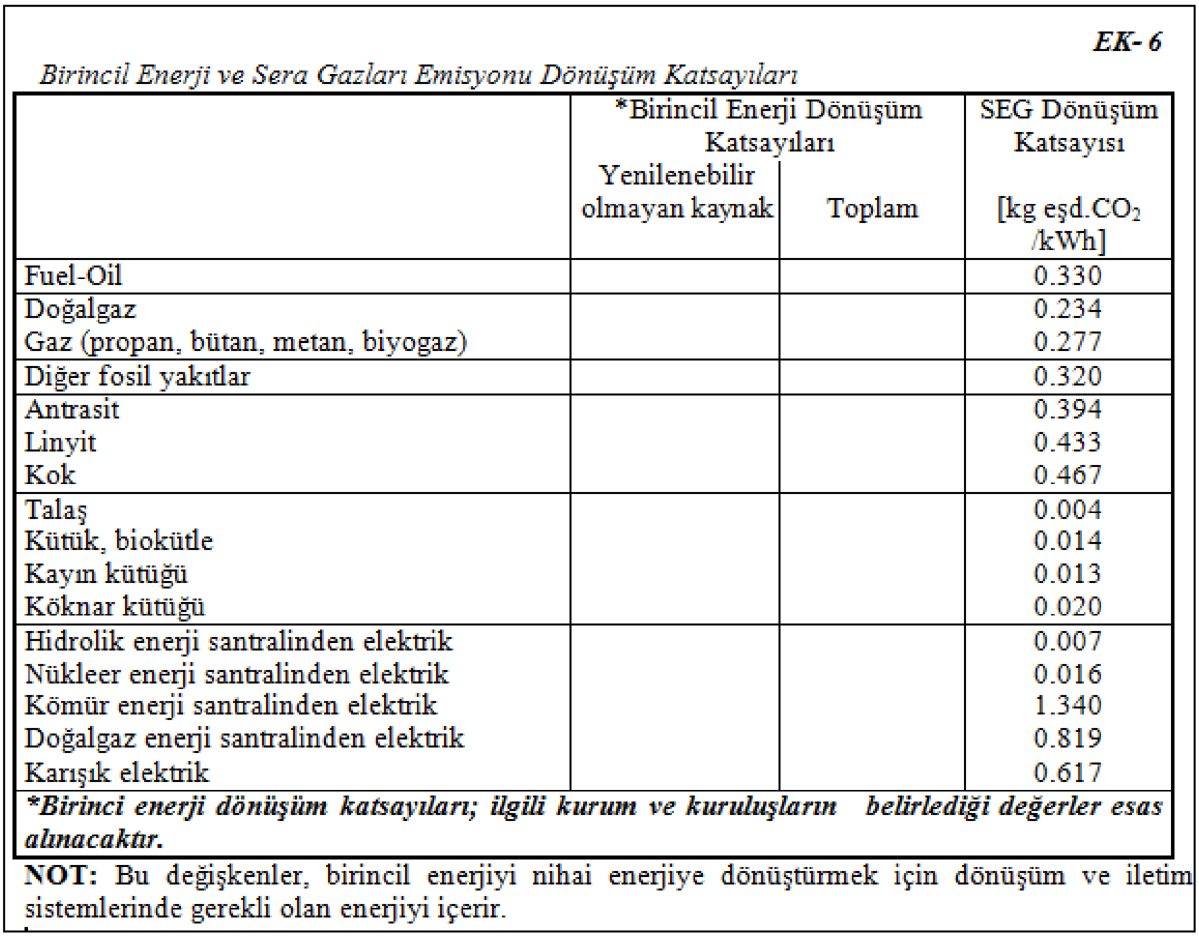
Table A.10. Heating cost for both insulated and non-insulated cases in four cities.

Fuel type	**Province**	**Annual Energy Loss* (kcal/h)**		**Fuel Lower Heating Value**	**Unit Fuel Price in December 2015 (TL/kg in Antalya, TL/m^3 in other cities)**	**Average Operational Efficiency Value**	**With Unit Fuel Price in December 2015 (TL/1000 kcal)**	**Annual Energy Consumption (TL)**		**Annual Energy Consumption Difference (TL)**
		No Insulation	**With Insulation**					**No Insulation**	**With Insulation**	
Natural Gas	Ankara	31082994.78	16922727.86	8250 kcal/m^3	1.2170720	85%	0.173558	5394.69	2937.07	2457.62
Bulk LPG	Antalya	12836755.06	7820990.26	11100 kcal/kg	5.5854780	92%	0.546952	7021.09	4277.71	2743.38
Natural Gas	Erzurum	44415084.01	20422850.39	8250 kcal/kg	1.1241330	85%	0.160304	7119.92	3273.87	3846.06
Natural Gas	Istanbul	24252255.94	13906678.61	8250 kcal/m^3	1.1929127	85%	0.170112	4125.61	2365.70	1759.91
*Annual Energy Loss is calculated from IZODER's TS 825 calculation tool.										

APPENDIX B: GREENHOUSE GAS EMISSION FACTORS

Greenhouse gas emission conversion factors of natural gas (0.234 kg eq. CO_2/kWh), bulk LPG (0.277 kg eq. CO_2/kWh) and electricity (0.617 kg eq. CO_2/kWh) are taken from the Regulation on Building Energy Performance (Official Gazette 05.12.2008, no: 27075).

Table B.1. Greenhouse gas emission conversion factors.



EK- 6

Birincil Enerji ve Sera Gazları Emisyonu Dönüşüm Katsayıları

	*Birincil Enerji Dönüşüm Katsayıları		SEG Dönüşüm Katsayısı
	Yenilenebilir olmayan kaynak	Toplam	[kg eşd.CO_2 /kWh]
Fuel-Oil			0.330
Doğalgaz			0.234
Gaz (propan, bütan, metan, biyogaz)			0.277
Diğer fosil yakıtlar			0.320
Antrasit			0.394
Linyit			0.433
Kok			0.467
Talaş			0.004
Kütük, biokütle			0.014
Kayın kütüğü			0.013
Köknar kütüğü			0.020
Hidrolik enerji santralinden elektrik			0.007
Nükleer enerji santralinden elektrik			0.016
Kömür enerji santralinden elektrik			1.340
Doğalgaz enerji santralinden elektrik			0.819
Karışık elektrik			0.617

****Birinci enerji dönüşüm katsayıları; ilgili kurum ve kuruluşların belirlediği değerler esas alınacaktır.***

NOT: Bu değişkenler, birincil enerjiyi nihai enerjiye dönüştürmek için dönüşüm ve iletim sistemlerinde gerekli olan enerjiyi içerir.

APPENDIX C: HOUSEHOLD APPLIANCES BRAND AND MODEL LIST

Household appliances brand and model list is shown in Table C.1.

Table C.1. Household appliances list.

appliance	**brand**	**model**	**energy consumption**	**energy performance class**	**price (TL)**
refrigerator (no frost)	İNDESİT	TAN 6 FNF D (TK)	471 kWh	A	1049
	İNDESİT	TN 6-402LT	639 kWh	B	899
washing machine	ARÇELİK	5063 F	0.85	A	834
	ARÇELİK	ARY 3320 S	1.01	B	665
dishwasher	ARÇELİK	6220 F	1.05	A	795
	ARÇELİK	ARY 6030 F	1.20	B	780
cooker with oven	ARÇELİK	9540 Y	2800 W	A	1095
	ARÇELİK	9430 Y	3500 W	B	1022

APPENDIX D: PHOTOVOLTAIC SYSTEM CALCULATIONS

PV system configuration, system requirements and related cost calculations are shown in Table D.1.

Table D.1. PV system configuration and cost calculations.

PV system	Unit	Amount	Materials unit price (TL)	Materials total price (TL)	Workmanship unit price (TL)	Workmanship total price (TL)	Total cost (TL)
PV panels construction	kW	2.55	645.10	1,645.00	0.00	0.00	1,645.00
PV panels (170Wp)	unit	15	1,151.50	17,272.50	0.00	0.00	17,272.50
2,5kW invertor	unit	1	4,606.00	4,606.00	0.00	0.00	4,606.00
Cabling, connectors and brakers	unit	1	618.52	618.52	0.00	0.00	618.52
Workmanship and other costs	unit	1	0.00	0.00	1,645.00	1,645.00	1,645.00
Total cost TL)				**24,142.02**		**1,645.00**	**25,787.02**
VAT (TL)				**4,345.56**		**296.10**	**4,641.66**
Total cost (VAT included) (TL)				**28,487.58**		**1,941.10**	**30,428.68**

APPENDIX E: SOLAR THERMAL SYSTEM CALCULATIONS

Solar thermal system configuration and system requirements are shown in Table E.1.

Table E.1. Solar thermal system configuration.

SYSTEM DATA	**Ankara**	**Antalya**	**Erzurum**	**Istanbul**
Global Radiation	1700.15 kWh	1795.15 kWh	1544.27 kWh	15032.26 kWh
DHW DEFAULT DATA				
Daily Consumption	200 l			
Desired Temperature	45 °C			
Load Profile	Detached House (evening max)			
COLLECTOR LOOP				
Manufacturer:	Buderus BBT Thermotechnik GmbH			
Type	Logasol SKE 2.0			
Number of Collectors	2			
Total Gross Area	4.74 m^2			
Tilt Angle	30.0 °			
Azimuth Angle	0.0 °			
TANK 1	Bivalent (Twin Coil) DHW Tank incl. Heating Element			
Manufacturer:	Buderus BBT Thermotechnik GmbH			
Type	Logalux SM300			
Volume	290 l			
AUXILIARY HEATING				
Manufacturer:	T*SOL Database			
Type	Electrical dwh Unit			
SIMULATION RESULTS	**Ankara**	**Antalya**	**Erzurum**	**Istanbul**
Total Irradiation onto Collector Surface	8.53 MWh	8.85 MWh	7.74 MWh	7.51 MWh
Specific Irradiation onto Collector Surface	1886.48 kWh/m^2	1958.21 kWh/m^2	1712.14 kWh/m^2	1661.34 kWh/m^2
Energy Produced by Collector Loop	2084.61 kWh	2067.11 kWh	1738.59 kWh	1870.50 kWh
Specific Energy Produced by Collector Loop	461.20 kWh/m^2	457.33 kWh/m^2	384.64 kWh/m^2	413.83 kWh/m^2
DHW Heating Energy Supply	2601.71 kWh	2100.79 kWh	2624.44 kWh	2486.98 kWh
Solar Contribution to DHW	2084.61 kWh	2067.11 kWh	1738.59 kWh	1870.50 kWh
Energy from Auxiliary Heating	980.61 kWh	628.59 kWh	1266.35 kWh	1033.06 kWh
DHW Solar Fraction	68.00%	76.70%	57.90%	64.40%
Total Solar Fraction:	68.00%	76.70%	57.90%	64.40%
System Efficiency	24.45%	23.35%	22.47%	24.91%

Investment cost of solar heating system is calculated from data obtained from market of producers of solar collector systems. These calculations are shown in Table E.2.

Table E.2. Solar thermal system cost calculations.

Production items	Amount	Unit	Brand	Unit price (TL)	Total cost (TL)
Solar collectors	2	unit	Buderus	706.89	1413.78
Boiler (300 lt)	1	unit	Buderus	1498.02	1498.02
Hydraulic control unit	1	unit	Buderus	548.23	548.23
Control module	1	unit	Buderus	191.03	191.03
Closed expansion tank (24 lt)	1	unit	APT	88.93	88.93
Safety valve 3/4"- 9 bar	1	unit	DUYAR	15.73	15.73
Safety valve 3/4"- 2,5 bar	1	unit	DUYAR	15.73	15.73
Brake bleeder unit	1	unit	Buderus	138.42	138.42
Connection set	1	unit	Buderus	118.15	118.15
Rooftop assembly set	2	unit	Buderus	169.83	339.66
Solar thermal fluid (10 lt)	1	unit	Buderus	72.72	72.72
Glass fibre reinforced PP-R (Polipropilen Random Copolimer) pipe Ø 25	12	meters	HAKAN	3.43	41.11
Glass fibre reinforced PP-R (Polipropilen Random Copolimer) pipe Ø 32	30	meters	HAKAN	5.15	154.54
Pipe assembly material	45%	%		195.65	88.04
Manometer (with 1/2" tap)	1	unit	PAKKENS	31.40	31.40
Ball valve 1/2"	2	unit	DUYAR	12.62	25.24
Ball valve 3/4"	2	unit	DUYAR	17.24	34.48
Ball valve 1"	6	unit	DUYAR	23.78	142.69
Silt trap 3/4"	1	unit	DUYAR	14.02	14.02
Silt trap 1"	1	unit	DUYAR	19.71	19.71
Check valve 3/4"	1	unit	DUYAR	15.02	15.02
Check valve 1"	1	unit	DUYAR	18.31	18.31
Total Cost (1 apartment) (VAT excluded) (TL)					**5024.94**
Total Cost (2 apartments) (VAT excluded) (TL)					**10049.89**
Total Cost (2 apartments) (VAT included) (TL)					**11858.87**

APPENDIX F: HEAT PUMP SYSTEM CONFIGURATION AND INVESTMENT COST CALCULATIONS

Heat pump system configuration and investment cost calculations for all for cities are shown in Table F.1-4.

Table F.1. Heat pump system configuration and investment cost in Ankara.

Production Items	Amount	Unit	Brand	Unit Price (TL)	Total Cost (TL)
Floor heating fittings					**13911.02**
Floor heating pipe	1100	m	REHAU	2.62	2878.54
Floor heating pipe installation plate	150	sqm	REHAU	19.60	2939.91
Inlet pipe connection	86	unit	REHAU	8.32	715.84
Cement finish additive	33	kg	REHAU	7.85	258.92
Insulating tape between plate ends	165	m	REHAU	2.69	443.21
Room thermostat	10	unit	REHAU	73.57	735.70
Room thermostat box	10	unit	REHAU	11.84	118.38
Collector HKV 07	1	unit	REHAU	398.64	398.64
Collector HKV 08	1	unit	REHAU	423.98	423.98
Control panel	1	unit	REHAU	119.17	119.17
Thermostatic valve	1	unit	REHAU	42.40	42.40
Collectors cabinet	2	unit		85.00	170.00
Insulation + cement finish + coating	1	set		4666.36	4666.36
Heat pump fittings					**44471.45**
Heat pump 26.9 kW	1	unit	LOGATERM	11628.14	11628.14
Valve connection set for heat pump	1	unit	LOGATERM	1368.96	1368.96
PE 100 Probe 32 x 2.9 (125 m/set)	400	m	REHAU	12.53	5012.14
PE Y-shaped muff pipe 32-32-40	6	unit	REHAU	40.98	245.90
Distance piece 32 x 2.9	125	unit	REHAU	18.58	2322.66
Type S modular collector	1	unit	REHAU	822.62	822.62
Modular collector - Pipe connection coupling set 40 x 3.7	3	unit	REHAU	49.69	149.08
Modular collector connection set 50 x 4.6	1	unit	REHAU	71.20	71.20
Collect PE 100 SDR 13 40 x 3.7	50	m	REHAU	4.95	247.38
PE Probe connection set	3	unit	REHAU	19.40	58.19
Probe weight 25 kg	3	unit	REHAU	275.25	825.74
Automatic control	1	gr.	REHAU	322.65	322.65
Vertical drilling	200	m		106.98	21396.80
Common fittings					**1886.44**
Fiber-reinforced PPR (polypropylene) pipe Ø 25	2	m	HAKAN	3.43	6.85
Fiber-reinforced PPR (polypropylene) pipe Ø 32	32	m	HAKAN	5.15	164.84
Fiber-reinforced PPR (polypropylene) pipe Ø 40	18	m	HAKAN	7.04	126.69
Pipe installation material	45%	%		298.38	134.27
Manometer (with 1/2" manometer tap)	1	unit	PAKKENS	31.40	31.40
Brake bleeder unit	2	unit	DUYAR	14.39	28.79
Air separator 1 1/4"	1	unit	Spirovent	123.73	123.73
Sludge and dirt separator 1 1/4"	1	unit	Spirovent	123.73	123.73
Closed expansion tank (200 lt-6 bar)	1	unit	Reflex	227.81	227.81
Closed expansion tank (250 lt-6 bar)	1	unit	Reflex	323.34	323.34
Relief Valve 3/4"- 2.5 bar	2	unit	DUYAR	16.14	32.27
Heat sensitive element (room/outdoor air)	2	unit		37.48	74.95
Ball valve 1"	4	unit	DUYAR	26.18	104.72
Ball valve 1 1/4"	4	unit	DUYAR	38.39	153.55
Ball valve 1 1/2"	3	unit	DUYAR	51.23	153.69
Silt trap 1 1/4"	1	unit	DUYAR	31.17	31.17
Silt trap 1 1/2"	1	unit	DUYAR	44.63	44.63
Total					**60268.91**

Table F.2. Heat pump system configuration and investment cost in Antalya.

Production Items	**Amount**	**Unit**	**Brand**	**Unit Price (TL)**	**Total Cost (TL)**
Floor heating fittings					**13125.97**
Floor heating pipe	800	m	REHAU	2.62	2093.48
Floor heating pipe installation plate	150	sqm	REHAU	19.60	2939.91
Inlet pipe connection	86	unit	REHAU	8.32	715.84
Cement finish additive	33	kg	REHAU	7.85	258.92
Insulating tape between plate ends	165	m	REHAU	2.69	443.21
Room thermostat	10	unit	REHAU	73.57	735.70
Room thermostat box	10	unit	REHAU	11.84	118.38
Collector HKV 07	1	unit	REHAU	398.64	398.64
Collector HKV 08	1	unit	REHAU	423.98	423.98
Control panel	1	unit	REHAU	119.17	119.17
Thermostatic valve	1	unit	REHAU	42.40	42.40
Collectors cabinet	2	unit		85.00	170.00
Insulation + cement finish + coating	1	set		4666.36	4666.36
Heat pump fittings					**31343.89**
Heat pump 13.1 kW	1	unit	LOGATERM	5781.68	5781.68
Valve connection set for heat pump	1	unit	LOGATERM	690.08	690.08
PE 100 Probe 32 x 2.9 (125 m/set)	300	m	REHAU	12.53	3759.10
PE Y-shaped muff pipe 32-32-40	6	unit	REHAU	40.98	245.90
Distance piece 32 x 2.9	125	unit	REHAU	18.58	2322.66
Type S modular collector	1	unit	REHAU	822.62	822.62
Modular collector - Pipe connection coupling set 40 x 3.7	3	unit	REHAU	49.69	149.08
Modular collector connection set 50 x 4.6	1	unit	REHAU	71.20	71.20
Collect PE 100 SDR 13 40 x 3.7	50	m	REHAU	4.95	247.38
PE Probe connection set	3	unit	REHAU	19.40	58.19
Probe weight 25 kg	3	unit	REHAU	275.25	825.74
Automatic control	1	gr.	REHAU	322.65	322.65
Vertical drilling	150	m		106.98	16047.60
Common fittings					**1886.44**
Fiber-reinforced PPR (polypropylene) pipe Ø 25	2	m	HAKAN	3.43	6.85
Fiber-reinforced PPR (polypropylene) pipe Ø 32	32	m	HAKAN	5.15	164.84
Fiber-reinforced PPR (polypropylene) pipe Ø 40	18	m	HAKAN	7.04	126.69
Pipe installation material	45%	%		298.38	134.27
Manometer (with 1/2" manometer tap)	1	unit	PAKKENS	31.40	31.40
Brake bleeder unit	2	unit	DUYAR	14.39	28.79
Air separator 1 1/4"	1	unit	Spirovent	123.73	123.73
Sludge and dirt separator 1 1/4"	1	unit	Spirovent	123.73	123.73
Closed expansion tank (200 lt-6 bar)	1	unit	Reflex	227.81	227.81
Closed expansion tank (250 lt-6 bar)	1	unit	Reflex	323.34	323.34
Relief Valve 3/4"- 2.5 bar	2	unit	DUYAR	16.14	32.27
Heat sensitive element (room/outdoor air)	2	unit		37.48	74.95
Ball valve 1"	4	unit	DUYAR	26.18	104.72
Ball valve 1 1/4"	4	unit	DUYAR	38.39	153.55
Ball valve 1 1/2"	3	unit	DUYAR	51.23	153.69
Silt trap 1 1/4"	1	unit	DUYAR	31.17	31.17
Silt trap 1 1/2"	1	unit	DUYAR	44.63	44.63
Total					**46356.29**

Table F.3. Heat pump system configuration and investment cost in Erzurum.

Production Items	Amount	Unit	Brand	Unit Price (TL)	Total Cost (TL)
Floor heating fittings					**13911.02**
Floor heating pipe	1,100	m	REHAU	2.62	2878.54
Floor heating pipe installation plate	150	sqm	REHAU	19.60	2939.91
Inlet pipe connection	86	unit	REHAU	8.32	715.84
Cement finish additive	33	kg	REHAU	7.85	258.92
Insulating tape between plate ends	165	m	REHAU	2.69	443.21
Room thermostat	10	unit	REHAU	73.57	735.70
Room thermostat box	10	unit	REHAU	11.84	118.38
Collector HKV 07	1	unit	REHAU	398.64	398.64
Collector HKV 08	1	unit	REHAU	423.98	423.98
Control panel	1	unit	REHAU	119.17	119.17
Thermostatic valve	1	unit	REHAU	42.40	42.40
Collectors cabinet	2	unit		85.00	170.00
Insulation + cement finish + coating	1	set		4666.36	4666.36
Heat pump fittings					**44471.45**
Heat pump 26.9 kW	1	unit	LOGATERM	11628.14	11628.14
Valve connection set for heat pump	1	unit	LOGATERM	1368.96	1368.96
PE 100 Probe 32 x 2.9 (125 m/set)	400	m	REHAU	12.53	5012.14
PE Y-shaped muff pipe 32-32-40	6	unit	REHAU	40.98	245.90
Distance piece 32 x 2.9	125	unit	REHAU	18.58	2322.66
Type S modular collector	1	unit	REHAU	822.62	822.62
Modular collector - Pipe connection coupling set 40 x 3.7	3	unit	REHAU	49.69	149.08
Modular collector connection set 50 x 4.6	1	unit	REHAU	71.20	71.20
Collect PE 100 SDR 13 40 x 3.7	50	m	REHAU	4.95	247.38
PE Probe connection set	3	unit	REHAU	19.40	58.19
Probe weight 25 kg	3	unit	REHAU	275.25	825.74
Automatic control	1	gr.	REHAU	322.65	322.65
Vertical drilling	200	m		106.98	21396.80
Common fittings					**1886.44**
Fiber-reinforced PPR (polypropylene) pipe Ø 25	2	m	HAKAN	3.43	6.85
Fiber-reinforced PPR (polypropylene) pipe Ø 32	32	m	HAKAN	5.15	164.84
Fiber-reinforced PPR (polypropylene) pipe Ø 40	18	m	HAKAN	7.04	126.69
Pipe installation material	45%	%		298.38	134.27
Manometer (with 1/2" manometer tap)	1	unit	PAKKENS	31.40	31.40
Brake bleeder unit	2	unit	DUYAR	14.39	28.79
Air separator 1 1/4"	1	unit	Spirovent	123.73	123.73
Sludge and dirt separator 1 1/4"	1	unit	Spirovent	123.73	123.73
Closed expansion tank (200 lt-6 bar)	1	unit	Reflex	227.81	227.81
Closed expansion tank (250 lt-6 bar)	1	unit	Reflex	323.34	323.34
Relief Valve 3/4"- 2.5 bar	2	unit	DUYAR	16.14	32.27
Heat sensitive element (room/outdoor air)	2	unit		37.48	74.95
Ball valve 1"	4	unit	DUYAR	26.18	104.72
Ball valve 1 1/4"	4	unit	DUYAR	38.39	153.55
Ball valve 1 1/2"	3	unit	DUYAR	51.23	153.69
Silt trap 1 1/4"	1	unit	DUYAR	31.17	31.17
Silt trap 1 1/2"	1	unit	DUYAR	44.63	44.63
Total					**60268.91**

Table F.4. Heat pump system configuration and investment cost in Istanbul.

Production Items	**Amount**	**Unit**	**Brand**	**Unit Price (TL)**	**Total Cost (TL)**
Floor heating fittings					**13387.65**
Floor heating pipe	900	m	REHAU	2.62	2355.17
Floor heating pipe installation plate	150	sqm	REHAU	19.60	2939.91
Inlet pipe connection	86	unit	REHAU	8.32	715.84
Cement finish additive	33	kg	REHAU	7.85	258.92
Insulating tape between plate ends	165	m	REHAU	2.69	443.21
Room thermostat	10	unit	REHAU	73.57	735.70
Room thermostat box	10	unit	REHAU	11.84	118.38
Collector HKV 07	1	unit	REHAU	398.64	398.64
Collector HKV 08	1	unit	REHAU	423.98	423.98
Control panel	1	unit	REHAU	119.17	119.17
Thermostatic valve	1	unit	REHAU	42.40	42.40
Collectors cabinet	2	unit		85.00	170.00
Insulation + cement finish + coating	1	set		4666.36	4666.36
Heat pump fittings					**41170.33**
Heat pump 26.9 kW	1	unit	LOGATERM	11628.14	11628.14
Valve connection set for heat pump	1	unit	LOGATERM	1368.96	1368.96
PE 100 Probe 32 x 2.9 (125 m/set)	350	m	REHAU	12.53	4385.62
PE Y-shaped muff pipe 32-32-40	6	unit	REHAU	40.98	245.90
Distance piece 32 x 2.9	125	unit	REHAU	18.58	2322.66
Type S modular collector	1	unit	REHAU	822.62	822.62
Modular collector - Pipe connection coupling set 40 x 3.7	3	unit	REHAU	49.69	149.08
Modular collector connection set 50 x 4.6	1	unit	REHAU	71.20	71.20
Collect PE 100 SDR 13 40 x 3.7	50	m	REHAU	4.95	247.38
PE Probe connection set	3	unit	REHAU	19.40	58.19
Probe weight 25 kg	3	unit	REHAU	275.25	825.74
Automatic control	1	gr.	REHAU	322.65	322.65
Vertical drilling	175	m		106.98	18722.20
Common fittings					**1886.44**
Fiber-reinforced PPR (polypropylene) pipe Ø 25	2	m	HAKAN	3.43	6.85
Fiber-reinforced PPR (polypropylene) pipe Ø 32	32	m	HAKAN	5.15	164.84
Fiber-reinforced PPR (polypropylene) pipe Ø 40	18	m	HAKAN	7.04	126.69
Pipe installation material	45%	%		298.38	134.27
Manometer (with 1/2" manometer tap)	1	unit	PAKKENS	31.40	31.40
Brake bleeder unit	2	unit	DUYAR	14.39	28.79
Air separator 1 1/4"	1	unit	Spirovent	123.73	123.73
Sludge and dirt separator 1 1/4"	1	unit	Spirovent	123.73	123.73
Closed expansion tank (200 lt-6 bar)	1	unit	Reflex	227.81	227.81
Closed expansion tank (250 lt-6 bar)	1	unit	Reflex	323.34	323.34
Relief Valve 3/4"- 2.5 bar	2	unit	DUYAR	16.14	32.27
Heat sensitive element (room/outdoor air)	2	unit		37.48	74.95
Ball valve 1"	4	unit	DUYAR	26.18	104.72
Ball valve 1 1/4"	4	unit	DUYAR	38.39	153.55
Ball valve 1 1/2"	3	unit	DUYAR	51.23	153.69
Silt trap 1 1/4"	1	unit	DUYAR	31.17	31.17
Silt trap 1 1/2"	1	unit	DUYAR	44.63	44.63
Total					**56444.42**

APPENDIX G: CALCULATION OF ANNUAL ENERGY CONSUMPTION OF HEAT PUMP

Calculation of annual energy consumption of heat pump is shown in Table G.1.

Table G.1. Annual energy consumption of heat pump.

Energy source of heat pump	**Province**	**Annual energy need (kWh)**		**Unit price of electricity (TL/kWh)**	**COP (coefficient of performance of heating)**	**Average Operational Efficiency Value**	**With Unit Fuel Price in December 2015 (TL/kWh)**		**Annual Energy Consumption (TL)**		**Annual Energy Consumption Difference (TL)**
		No Insulation	**With Insulation**						**No Insulation**	**With Insulation**	
Electricity	Ankara	36143.02	19677.59	0.41	3.25	99%	0.41 / (3.25 x 0.99)	0.127428	4605.64	2507.48	2098.16
Electricity	Antalya	14926.46	9094.17	0.41	3.25	99%	0.41 / (3.25 x 0.99)	0.127428	1902.05	1158.85	743.20
Electricity	Erzurum	51645.45	23747.50	0.41	3.25	99%	0.41 / (3.25 x 0.99)	0.127428	6581.08	3026.10	3554.98
Electricity	Istanbul	28200.30	16170.56	0.41	3.25	99%	0.41 / (3.25 x 0.99)	0.127428	3593.51	2060.58	1532.93

APPENDIX H: SORTED ENERGY EFFICIENCY MEASURES ACCORDING TO RELATED SAVING TYPES

Table H.1. Energy cost saving of energy efficiency measures in Ankara.

Ankara		
order	**Energy Efficiency Measures**	**Energy Cost (TL)**
1	**Insulation (EPS) & Roof (Rockwool)**	2457.62
2	**PV Panels**	1332.50
3	**Ground Source Heat Pump**	789.05
4	**Solar Panels**	721.10
5	**Energy Efficient Lighting**	643.54
6	**Energy Efficient Appliances**	275.35

Table H.2. Energy saving of energy efficiency measures in Ankara.

Ankara		
order	**Energy Efficiency Measures**	**Energy (kwh)**
1	**Ground Source Heat Pump**	24909.76
2	**Insulation (EPS) & Roof (Rockwool)**	16465.43
3	**PV Panels**	3250.00
4	**Solar Panels**	1758.78
5	**Energy Efficient Lighting**	1569.60
6	**Energy Efficient Appliances**	671.60

Table H.3. Carbon saving of energy efficiency measures in Ankara.

Ankara		
order	**Energy Efficiency Measures**	**CO_2 Emissions (kg eq. CO_2)**
1	**Insulation (EPS) & Roof (Rockwool)**	3852.91
2	**PV Panels**	2005.25
3	**Ground Source Heat Pump**	1526.54
4	**Solar Panels**	1085.17
5	**Energy Efficient Lighting**	968.44
6	**Energy Efficient Appliances**	414.37

Table H.4. Energy cost saving of energy efficiency measures in Antalya.

Antalya		
order	**Energy Efficiency Measures**	**Energy Cost (TL)**
1	**Ground Source Heat Pump**	5119.04
2	**Insulation (EPS) & Roof (Rockwool)**	2743.38
3	**PV Panels**	1476.82
4	**Solar Panels**	1009.76
5	**Energy Efficient Lighting**	643.54
6	**Energy Efficient Appliances**	275.35

Table H.5. Energy saving of energy efficiency measures in Antalya.

Antalya		
order	**Energy Efficiency Measures**	**Energy (kwh)**
1	**Ground Source Heat Pump**	10287.31
2	**Insulation (EPS) & Roof (Rockwool)**	5832.28
3	**PV Panels**	3602.00
4	**Solar Panels**	2462.82
5	**Energy Efficient Lighting**	1569.60
6	**Energy Efficient Appliances**	671.60

Table H.6. Carbon saving of energy efficiency measures in Antalya.

Antalya		
order	**Energy Efficiency Measures**	**CO_2 Emissions (kg eq. CO_2)**
1	**PV Panels**	2222.43
2	**Insulation (EPS) & Roof (Rockwool)**	1615.54
3	**Solar Panels**	1519.56
4	**Ground Source Heat Pump**	1272.27
5	**Energy Efficient Lighting**	968.44
6	**Energy Efficient Appliances**	414.37

Table H.7. Energy cost saving of energy efficiency measures in Erzurum.

Erzurum		
order	**Energy Efficiency Measures**	**Energy Cost (TL)**
1	**Insulation (EPS) & Roof (Rockwool)**	3846.05
2	**PV Panels**	1358.33
3	**Energy Efficient Lighting**	643.54
4	**Ground Source Heat Pump**	538.84
5	**Solar Panels**	486.79
6	**Energy Efficient Appliances**	275.35

Table H.8. Energy saving of energy efficiency measures in Erzurum.

Erzurum		
order	**Energy Efficiency Measures**	**Energy (kwh)**
1	**Ground Source Heat Pump**	35594.02
2	**Insulation (EPS) & Roof (Rockwool)**	27897.95
3	**PV Panels**	3313.00
4	**Energy Efficient Lighting**	1569.60
5	**Solar Panels**	1187.30
6	**Energy Efficient Appliances**	671.60

Table H.9. Carbon saving of energy efficiency measures in Erzurum.

Erzurum		
order	**Energy Efficiency Measures**	**CO_2 Emissions (kg eq. CO_2)**
1	**Insulation (EPS) & Roof (Rockwool)**	6528.12
2	**Ground Source Heat Pump**	2181.31
3	**PV Panels**	2044.12
4	**Energy Efficient Lighting**	968.44
5	**Solar Panels**	732.56
6	**Energy Efficient Appliances**	414.37

Table H.10. Energy cost saving of energy efficiency measures in Istanbul.

Istanbul		
order	**Energy Efficiency Measures**	**Energy Cost (TL)**
1	**Insulation (EPS) & Roof (Rockwool)**	1759.91
2	**PV Panels**	1292.73
3	**Solar Panels**	678.09
4	**Energy Efficient Lighting**	643.54
5	**Ground Source Heat Pump**	532.10
6	**Energy Efficient Appliances**	275.35

Table H.11. Energy saving of energy efficiency measures in Istanbul.

Istanbul		
order	**Energy Efficiency Measures**	**Energy (kwh)**
1	**Ground Source Heat Pump**	19435.64
2	**Insulation (EPS) & Roof (Rockwool)**	12029.74
3	**PV Panels**	3153.00
4	**Solar Panels**	1653.88
5	**Energy Efficient Lighting**	1569.60
6	**Energy Efficient Appliances**	671.60

Table H.12. Carbon saving of energy efficiency measures in Istanbul.

Istanbul		
order	**Energy Efficiency Measures**	**CO_2 Emissions (kg eq. CO_2)**
1	**Insulation (EPS) & Roof (Rockwool)**	2814.96
2	**PV Panels**	1945.40
3	**Ground Source Heat Pump**	1191.07
4	**Solar Panels**	1020.44
5	**Energy Efficient Lighting**	968.44
6	**Energy Efficient Appliances**	414.37