A COMPARATIVE ANALYSIS OF EFFICIENCY AND CARBON DIOXIDE MITIGATION POTENTIAL OF RESIDENTIAL HEATING SYSTEMS IN BURSA (TURKEY)

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ABSTRACT

A COMPARATIVE ANALYSIS OF EFFICIENCY AND CARBON DIOXIDE MITIGATION POTENTIAL OF RESIDENTIAL HEATING SYSTEMS IN BURSA (TURKEY)

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The main objective of this study is to develop a methodology by using the actual data of residential natural gas consumption in order to compare the efficiency levels of the three different residential heating systems. Such comparison is considered crucial to support better policy-making. Since final consumers are the subscribers of natural gas distribution companies regulated by Energy Market Regulatory Authority of Turkey, natural gas distribution market conditions and related regulations are taken into the account while developing the methodology. This is also expected that the methodology would be usefull for similar studies for different natural gas distrubition regions of Turkey.

Apartments constitute a larger share of Turkeys housing stock. Three residential heating systems prevail in most of these apartment blocks: standalone heating systems (individual unit based), central heating systems (block based) and district heating systems (neighborhood based). In this research, apartment blocks with these three different heating systems are examined in order to compare energy efficiency of and carbon dioxide emissions from their heating systems. Natural gas based residential heating systems are particularly dealt with due to data availability and extensive use. Results of the comparative analysis are applied to citywide housing stock data so as to find out the potential emission reductions in case widespread use of central and district heating systems are achieved in cities of Turkey.

Key Words: energy efficiency, climate change, carbon dioxide emissions, residential heating systems, natural gas distrubition, Bursa City

ÖZ

BURSA İLİNDE KONUT ISITMA SİSTEMLERİNİN ENERJİ VERİMLİLİĞİ VE KARBONDİOKSİT SALIMI AZALTIM POTANSİYELLERİNİN KARŞILAŞTIRMALI ANALİZİ

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Bu çalışmada gerçek doğal gaz tüketim verileri üzerinden farklı konut ısıtma sistemlerinin enerji verimlilikleri ile karbon salımlarının karşılaştırılabilmesi amacı ile bir metodoloji geliştirilmektedir. Geliştirilen metodolojinin, Türkiye genelinde de uygulanabilir olması gözetilerek, Enerji Piyasası Düzenleme Kurumu mevzuatına tabi doğal gaz dağıtım şirketlerinin faaliyet gösterdikleri her bir dağıtım bölgesinde erişilebilecek veriler kullanılarak sonuç vermesi beklenmektedir.

Bilindiği gibi, Türkiye konut stokunun önemli bir bölümünü apartmanlar oluşturmaktadır. Apartman tipi konut yapılarının ısıtılmasında ise yaygın olarak üç farklı sistem kullanılmaktadır: Tekil (Kombili) Isıtma Sistemi, Merkezi Isıtma Sistemi ve Bölgesel Isıtma Sistemi. Bu çalışmada, Bursa özelinde, bu üç farklı sistem ile ısıtılan benzer özellikteki konut yapıları (apartmanlar) seçilerek, enerji verimlilikleri ile ısıtmadan kaynaklanan karbondioksit emisyonları karşılaştırılmaktadır. Çalışmada veri elde etme kolaylığı ve kullanım yaygınlığı nedeniyle doğal gaz ile ısıtılan konut yapıları incelenmektedir. Elde edilen sonuçlar üzerinden kent düzeyinde konut stoku temel alınarak verimlilik analizleri yapılmakta ve ülkemiz kentlerinde merkezi ve bölgesel sistemlere geçilmesi halinde gerçekleştirilebilecek olası emisyon azaltımları geliştirilen metodoloji çerçevesinde hesaplanabilmektedir.

Anahtar Kelimeler: enerji verimliliği, iklim değişikliği, karbondioksit emisyonları, konut ısıtma sistemleri, doğal gaz dağıtım, Bursa

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Dedicated to my brother

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ABBREVIATIONS

ABPRS: Address Based Population Registration System

BAU: Towards a Green Economy BAU Scenario, UNEP

BBS: Number of Detached Section, EMRA

BOTAŞ: Turkish Petroleum Pipeline Corporation

CH: Central Heating

CO_2: Carbondioxide

CPS: Current Policies Scenari, IEA

DH: District Heating

EPDK: Enerji Piyasası Düzenleme Kurumu, EMRA

EMRA: Energy Market Regulatory Authority

EU: European Union

GIS: Geographical Information System

G2: Towards a Green Economy G2 Scenario, UNEP

GEA: Global Energy Assessment

HDD: Heating Degree Days

IEA: International Energy Agency

IH: Individual Heating

IPCC: The Intergovernmental Panel on Climate Chang

IPCC-AR5: Fifth Assessment Report of IPCC

KWES: Key World Energy Statistisc, IEA

Mtoe: Million tons of oil equivalent

NPS: New Policies Scenario

REMM: Rational Exergy Management Model

TPAO: The Turkish Petroleum Corporation

TS: Turkish Standard

TUIK: Turkish Statistical Institute

UNEP: United Nations Environment Programme

WAM: Weighted Arithmetic Mean

WOE: World Energy Outlook, IEA

CHAPTER 1

INTRODUCTION

Energy Efficiency is defined as receiving more products or services for the same energy input. With the projections being made, it has become apparent that one of the most important components of the increase in energy demand is the ever-increasing demand for natural gas. Due to its chemical structure, natural gas is considered to be more environmentally-friendly than other fossil-based fuels. It should also be taken into consideration that natural gas is a fossil fuel and that there are no domestic reserves of natural gas in Turkey. It is considered that it is important to provide efficiency in all areas utilizing natural gas, residential heating systems in particular, with regard to management of energy demand, increasing the security for supply and successfully implementing the policies developed to counter seasonal changes.

More than 25% of the total generated energy in the World is consumed in the residential sector. It is seen that this percentage in Turkey is approximately 35%. According to the data from IEA, it is understood that buildings, which rank second after the industrial sector in energy consumption, are only able to utilize 20% of their potential in energy efficiency[1].

The local natural gas distribution activity began in 1988 in Turkey. Due to the natural gas distribution license tenders made by Energy Market Regulatory Authority

[1] Kılkış, Ş. "Net-Sıfır Binalar ve Kentler İçin Akılcı Ekserji Yönetim Modeli", 11. Ulusal Tesisat Mühendisliği Kongresi, Yüksek Performanslı Binalar Sempozyumu Bildirileri, İzmir, 2013, p. 1603-1610

(EMRA) since 2003, the coverage of the distribution network has expanded to 76 cities covered by 69 natural gas distribution regions. The 95% of subscribers of companies with license located within the currently available natural gas distribution regions are residential. Therefore, it is clear that residential natural gas consumption efficiency is of the utmost importance for the Natural Gas Market of Turkey.

It is apparent that the energy efficiency regulation is designed to cover a large area with the intention of being holistic. In addition to The Ministry of Energy and Natural Resources and The Ministry of Environment and Urbanization, which are the primary organizations to implement the regulation regarding energy efficiency in residences, the importance and necessity of communication between these organizations is emphasized by the regulation.

Nearly 80% of the approximately 9 million residential subscribers in natural gas distribution sector are using individual kombi boiler heating systems. This rate can be seen more dramatically for Bursa city, which is the case study city of this research. According to the data provided by the Bursa Natural Gas Distribution Company (BURSAGAZ), 94% of residential consumers use individual heating systems, while central heating has 5% and district heating system has 1% shares.

Within the scope of the differences between three common heating systems, existing levels of natural gas consumptions and related carbon dioxide (CO_2) emissions can be evaluated. The main objective of this study is to develop a methodology by using the actual data of residential natural gas consumption in order to compare the efficiency levels of the three different residential heating systems; individual, central and district heating systems. Such comparison is considered crucial to support better policy-making. Since final consumers are the subscribers of natural gas distribution companies regulated by EMRA, natural gas distribution market conditions and related regulations are taken into the account while developing the methodology.

As part of the case study, three buildings, which have individual heating (IH), central heating (CH) and district heating (DH) systems, are selected as sample buildings.

Natural gas consumption levels and heating areas of the sample buildings are infiltrated through the database of the Natural Gas Distribution Company. By using national standards for heating load (TS 2116) and heat insulation (TS 825) of buildings, the augmentations and adjustments are applied to the actual data in order to make the comparison among the three sample buildings possible. Natural gas consumption and associated CO_2 emissions are calculated for unit area of IH, CH and DH system samples. Results of the comparative analysis are then taken as a basis for a citywide estimation by using the housing stock data for Bursa city. For the shares of IH, CH and DH system users in the entire city, some projections have been made with the perspective of policymaking.

In this research, efficiency comparisons are handled not only over quantity, but also with Rational Exergy Management Model[2] subjects in order to prepare the foundation for studies involving the possibility for delivery of more services for the same energy input. In cases where the quantity of natural gas with a high energy quality is dependent on limited reserves, an increase of efficiency in the available systems would result in multilateral gains. This study emphasizes the need for a more effective utilization of natural gas' exergy on available engineering application

1.1. Related Concepts and Definitions

Energy efficiency is defined as decreasing the consumption of energy as low as possible without reducing the quantity or quality of production and without having any negative effects on social welfare. In other words, energy efficiency is the reduction in energy consumption per unit of service or product without causing a decrease in life standards and service qualities in buildings and without causing a decrease in production quality and quantity in industrial operations[3]. Another definition of energy efficiency would be supplying the equal amount of work by

[2] Kılkış, B. Kılkış, Ş. "Upgrading EU Directive With Raitonal Exergy Model", ASHRAE Transactions Volume 113, Part 2, 2007, p. 181-191.
[3] Yunus A. Çengel, "Tükenmez Bir Enerji Kaynağı Olarak Enerji Verimliliği", NuRER-2009 Conference Proceedings, Turkish Science Research Foundation TÜBAV, Ankara, 2009, p. 23.

using less energy without reducing life standards, production quality and production quantity by utilizing new technologies. In essence, energy efficiency can be defined as reducing energy consumption amounts per product quantity. On the other hand, the International Energy Agency (IEA) defines energy efficiency as producing more services with the same energy input, while it is emphasized that it is an important method in energy consumption management and having energy consumption under control[4].

In Turkey, under the regulation in force, energy efficiency is defined the most comprehensively in the introduction section of "Energy Efficiency Strategy Document 2012-2023". The Strategy Document was prepared with the participation of various agencies in public and private sectors as well as of non-governmental organizations under the coordination of The Ministry of Energy and Natural Resources. The document was approved by the Higher Planning Council on 25 February 2012, while it was published in the Official Gazette with the number 28215. In the following section in which this document will be discussed in detail, energy efficiency is defined as: "*...a concept that defines national strategic goals such as providing security in energy supply, reducing risks related to dependence to imports, providing sustainable energy costs, increasing the effectiveness of the fight against climate change and environmental protection".* In the following parts of the description, statements such as "*...as the importance of sustainable development is increasingly being understood in today's World, the value of the effort towards energy efficiency is increasing proportionally. In this case; increasing the energy efficiency in every stage from energy generation and transmission to final consumption, preventing wasting and insensible consumption, reducing energy consumption on the basis of sectors or macro levels as suitable are important components with high priorities for our national energy policy*[5]." can be found.

When *Energy Efficiency in Residences* is the subject, the aim is to reduce energy consumption to a minimum level while maintaining the level of comfort within the

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[4] IEA, Energy Efficiency, http://www.IEA.org/topics/energyefficiency/

[3] T.C. Yüksek Planlama Kurulu, Enerji Verimliliği Strateji Belgesi 2012-2023, Resmî Gazete, 25.02.2012-28215

residence. The energy used in residences with natural gas is obtained from the heat energy obtained from natural gas and the available systems provide the needs for heating, the kitchen and hot water. In this regard, the objective of energy efficiency for natural gas heating systems can be simply described as maintaining the available comfort by consuming less natural gas. As a summarized definition, energy efficiency in residences with natural gas is the provision of more work or benefits by per one unit of natural gas consumed.

Beside energy efficiency, exergy can be defined as the quality of energy and the potential for work. In this regard, even though natural gas and hot water with the same energy are equal in quantity in terms of energy, a difference in quality can be observed. This difference that is the result of the potential for work is crucial for the quality of energy to come into prominence. For this reason, in addition to efficient consumption in terms of the quantity of the fuel that is going to provide the energy needs in engineering applications, it appears that it is necessary to utilize the quality efficiently as well. In this case, exergy can be defined as energy quality that is irreversible and must be utilized instantly that it is generated.

In this regard, for any of the IH, CH or DH systems using natural gas, it is observed that the direct usage of fuel with a high exergy value in locale heating is inefficient. With the Rational Exergy Management Model, being able to convert the natural gas entering the system into electricity with the exergy value accepted as 1 and utilizing the resulting waste heat for locale heating and similar alternative areas demonstrates the importance in the basis of the second law. For district heating systems in energy intensive industries where the primary product is not electricity, waste heat can be utilized.

With cogeneration systems also known as combined heat and power generation systems, it is possible to implement smart exergy management model applications in residential heating. This results in an increase in the cumulative efficiency of locale heating. In addition, alternative greenhouse gas emission costs are reduced by 30% for residences, which comprise 15% of CO_2 emissions related to fuel consumption in

Turkey[6]. In this case, it is evaluated that making arrangements in the regulation for micro-cogeneration applications for residences with natural gas can be considered. It is also apparent that taking measures for district heating system applications in the efficiency regulation would be significantly beneficial.

[6] Evren, N. E Enerji Verimliliği ve Ekserji Kuramı, Enerji Verimliliği Açısından Doğal Gaz ve Konutlarda Enerji Verimliliği, Expertise Thesis, EMRA, 2014

CHAPTER 2

ENERGY EFFICIENCY
AS A POLICY MAKING INSTRUMENT

In addition to increasing energy demand due to general economic growth, environmental concerns including global warming and climate change has led World’s nations to search for alternative and clean energy resources. For this reason, the importance of energy efficiency, also defined as *"an inexhaustible energy resource*[7]*"* is gradually becoming more apparent.

Given the dependency on fossil fuels in European countries with intensive energy consumption along with insufficient national resources, energy efficiency has become a hot topic in the course of providing security for energy supply. In this regard, it can be observed that energy efficiency has recently become an important goal in energy policies followed by the World’s nations.

In this chapter, the concept of energy efficiency, both in general and in residential sector, will be considered and discussed. The ways of meeting the increasing demand for energy, providing security for supply, reducing foreign dependency and the need for a policy towards reducing greenhouse gas emissions and impacts of climate change will be focused on and argued. Furthermore, the possible effects of improvements, the objectives for energy efficiency, and gains of efficiency measures will be evaluated.

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[5] Çengel, Ibid p. 23-29

2.1. Increasing Energy Demand and Energy Efficiency

Due to the increase in population around the World, in parallel to urban development and industrialization, the primary energy consumption is gradually increasing. The increase in population and income per person are the main factors for the increase in energy consumption. Projections indicate that the World's population will reach 8.3 billion by 2030[8]. This means that there will be a need for energy supply for an additional 1.3 billion people compared to current circumstances. On the other hand, for available economical systems, there is also an increase for energy demand independent of economic development and population growth and certain scenarios are being developed to forecast the increasing energy demand. This study will include three different scenarios from the World Energy Outlook (WEO) 2010 Report published by the International Energy Agency (IEA) in 2010, which are frequently referenced in literature.

Current Policies Scenario (CPS) involve ongoing situations in energy policies currently being enforced, *New Policies Scenario* (NPS), on the other hand, involves results calculated with data that foresees a cautious approach composed also by taking commitments for the reduction in greenhouse gas emissions and removal of subsidies for fossil fuels into consideration. *450 ppm Scenario* sets out an energy pathway consistent with the goal of limiting the global increase in average temperatures to 2°C by limiting concentration of greenhouse gases in the atmosphere to around 450 parts per million of CO_2[9]. As it can be seen in Figure 2.1, for each three scenarios the value of the energy demand by 2035 measured in million tons oil equivalent, are indicative of the differences in demand to occur due to the implementation of energy policies.

[8] IEA, "Golden Age of Gas", World Energy Outlook Special Report, 2011
[9] IEA, "World Energy Outlook 2010 - (WEO)", 2010

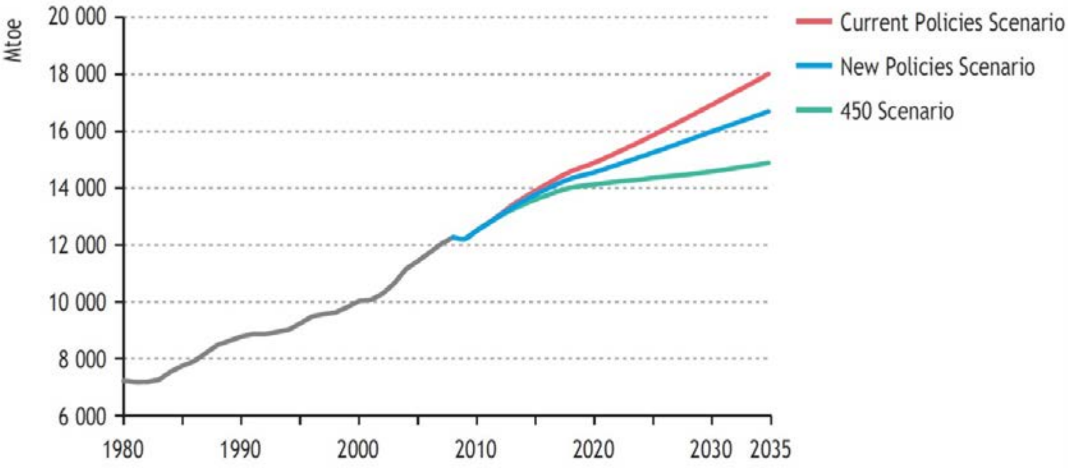


Figure 2.1. World primary energy demand by scenario (WEO, 2010)

In WEO of 2012, the gains of the differences in total primary energy demand from current policy scenarios to new policy scenarios and from new policy scenarios to the 450 ppm scenario is remarked and it is emphasized that for both comparisons the final consumer energy efficiency there will be 66-67% gain in projections for 2035. In comparisons in scenarios in question, it is observed that projections towards economical efficacies with the fuel and technology changes are far behind final consumer efficiency.

Moving on from this evaluation, it is seen that energy efficiency is placed in the center in another scenario found in 2012's World Energy Outlook. In this regard, a methodology towards realization of the energy efficiency potentials by considering it as a holistic approach and with applicable efficiency measures, which have been partly evaluated in the new policies and 450 ppm scenarios published in 2010, are being presented. According to the projection named *Efficient World Scenario*, there is three times more potential for economic gains in the energy efficiency potential, which is evaluated in new policy scenarios. The possible savings based on the energy efficiency potentials of the scenarios can be seen on Figure 2.2. According to the IEA data the total saving potential regarding to improve energy efficiency is 66-67 % for end use sector in between different scenarios.

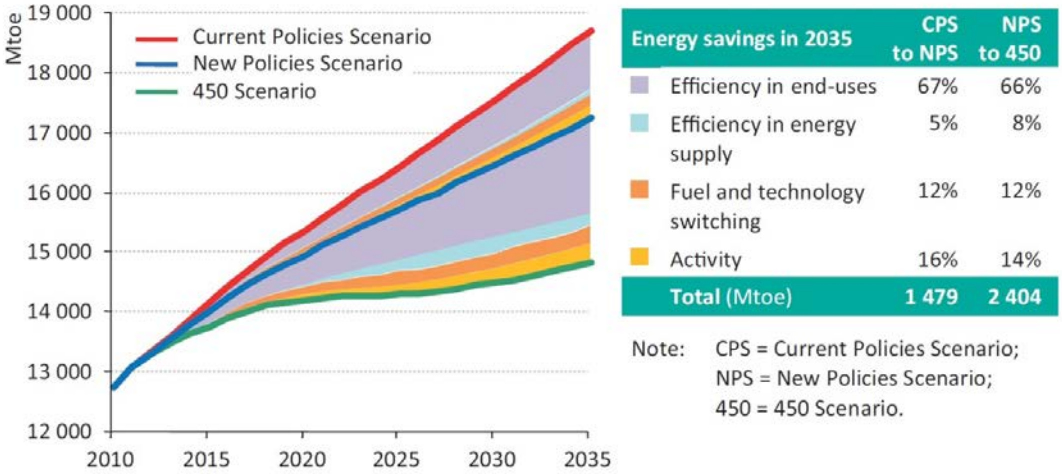


Figure 2.2. Change in global primary energy demand by measure and by scenario (WEO, 2012)

When the new policy scenarios' energy demand predictions for 2035 and the efficient World scenario is compared in terms of primary energy sources, the apparent gains are reported as 1350 Million tons of oil equivalent (Mtoe) for coal, 12.7 million barrels per day (mb/d) for petrol and 680 billion cubic meters (bcm) for natural gas.

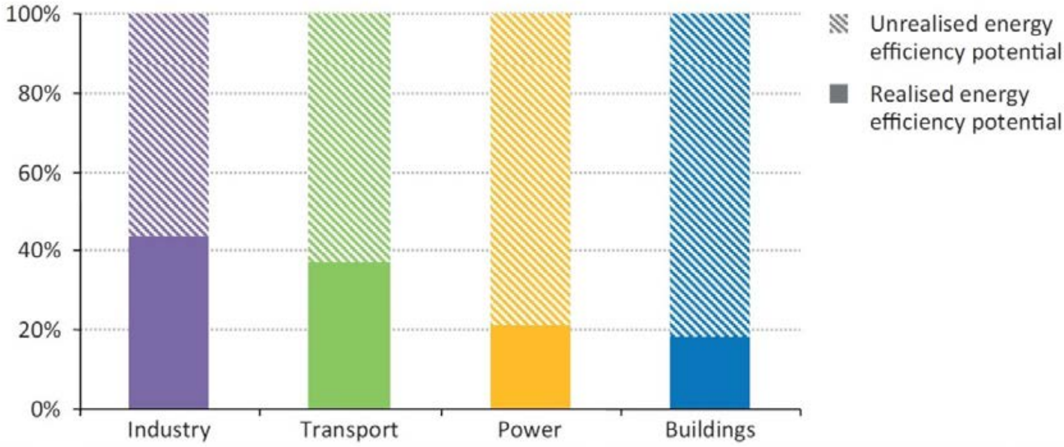
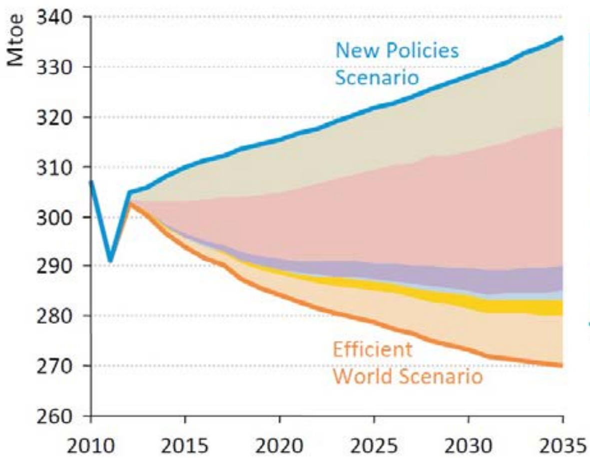


Figure 2.3. Utilized long-term energy efficiency economic potential in the New Policies Scenario, 2011-2035 (WEO, 2012)

As it can be seen in Figure 2.4, it is evaluated that by properly utilizing the energy efficiency potential, environmental and technical problems from economical loads that are brought by the increasing energy demand can be significantly avoided. It is apparent that increasing demand for primary energy consumption can be halved compared to the efficient World scenario and new policies scenario. The efficiency applications that present differences for the two scenarios can, for example, reduce the price of petrol per barrel by 15 dollars in the same period when savings occur due to the reduction for petroleum demand[10]. In this case, it is stated in the 2012's World Energy Outlook that thanks to the overseeing of the increased efficiency by sectors in the efficient World scenario the total output for EU by year 2035. It can be said that only the efficiency potential of heating systems in Europe leads to 15 Mtoe energy savings by efficient World scenario.



Fuel savings	Mtoe 2020	Mtoe 2035	Share 2020	Share 2035
Insulation*	10	18	34%	27%
Space heating	13	28	43%	42%
Appliances	2	5	7%	8%
Cooling	0	2	1%	2%
Lighting	1	3	3%	5%
Others	4	10	13%	15%

* Includes energy management systems.

Figure 2.4. EU energy demand and savings in the residential sector in the Efficient World Scenario relative to the New Policies Scenario (WEO, 2012)

From a wider perspective, considering the data evaluated by taking into account all the sectors to create energy demand, it is possible to evaluate cumulative effects of the increase in energy efficiency in transportation, industry, electricity generation, and buildings in a holistic manner. In addition to this, to detect the place of the

[10] IEA, "World Energy Outlook 2012 - (WOE)", *2012*

energy consumed in buildings, which comprises the actual subject in this study, in the increase in energy demand, it is considered that it would be sensible to look at the final consumption projections of 2035 based on the sector according the mentioned current policies scenarios and 450 ppm scenarios.

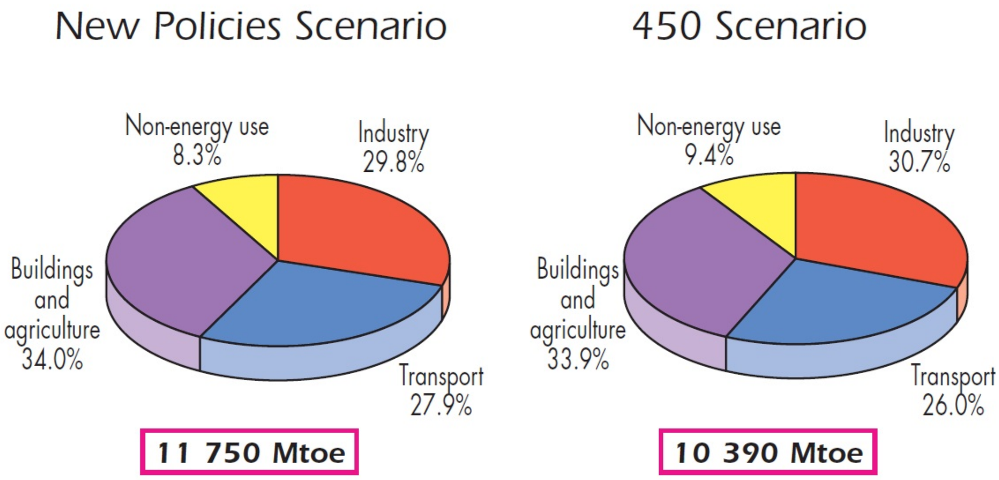


Figure 2.5. Total final consumption of World by sector in 2035 (KWES, 2013)

Table 2.1. Weight of Final Energy Consumption for Buildings (Pe´rez, 2008)

Final Energy Consumption (%)	Commercial	Residential	Total
USA	18	22	40
United Kingdom	11	28	39
European Union	11	26	37
Spain	8	15	23
World	7	16	24

When considering the data found in energy statistics published every year by the International Energy Agency (*Key World Energy Statistics, KWES, 2013)*, it is possible to have an idea on where residential sector stands in the sector-based total final consumption data. As it can be seen in Figure 2.4, the distribution for both scenarios have similar properties and the share of buildings and agriculture is around 34%. In addition to not being able to fully determine where the residential sector and heating systems stand within the subject of final energy consumption, a research done by Luis Pe'rez-Lombard and his friends stated that, globally, the final energy consumption is 24% for buildings, of which 16% belongs to residences[11]. In Table-2.1, the percentage that belongs for residences in the final energy consumption for the United Kingdom is 28%, and 26% in the European Union[12].

These data statistics that are comprised of heating, cooling, illumination, hot water, electrical equipment and all other kinds of energy consumptions for residences and commercial structures. It would be suitable to analyze the graph found in Figure 2.5 in order to determine the energy amounts of the heating systems in residential buildings. In the study based on the graph, the Heating Degree Days (HDD), which are different for USA, Canada, Germany, UK, France and Japan, have been reduced to 2700 HDD and for the 2700 heating days, the residential energy consumption per person are being compared in terms of heating, hot water, kitchen, illumination and housewares[13]. In Figure 2.5, it can be seen that the most significant part in residential energy consumption are heating systems, which is the focus of this research.

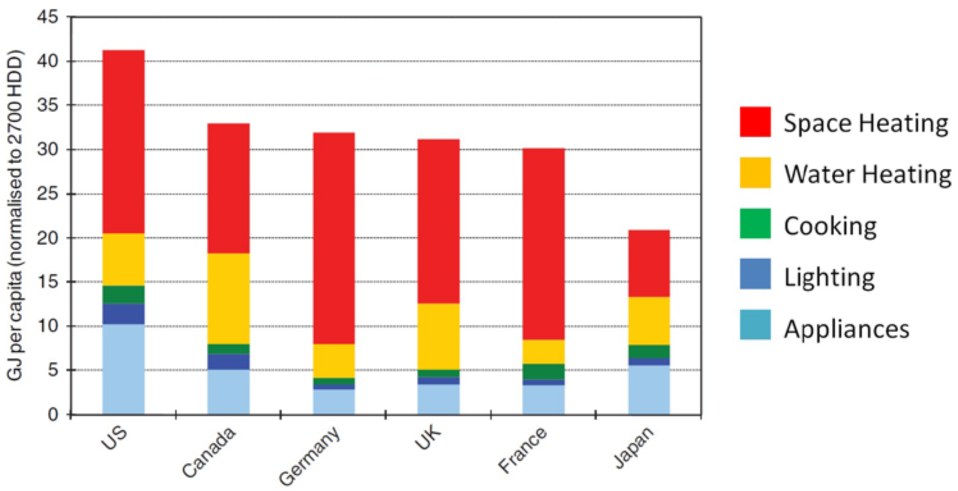


Figure 2.6. Residential energy use in different developed countries (GEA, 2012)

[11] L. Pe´rez-Lombard, Pout Ortiz, "A Review On Buildings Energy Consumption Information", Energy and Buildings 40, 2008, p. 394–398
[12] Ibid Table-3.
[13] GEA, "Global Energy Assessment - Toward a Sustainable Future", Cambridge University Press, Cambridge, UK and New York, NY, USA and the International Institute for Applied Systems Analysis, Laxenburg, Austria, 2012, p. 663.

These statistical data shows the share of residential heating systems stands in the total energy demand. Furthermore it can be clearly seen the significance of energy efficiency as an important instrument for policy making for every area that consumes energy for the balancing of the increasing energy demand.

When it is thought that the increasing energy demand is a more critical matter for developing economies compared to developed countries, in addition to having policies enforced as increasing energy sources and creating varieties, keeping the demand under control should be evaluated in order to meet these demands. In this regard, it can be seen that having the work to developing strong policies and applications, directed towards energy efficiency to control the increasing energy demand, made in a sensitive manner is of vital importance. It is observed that heating systems of buildings, especially residential buildings that is the subject of this study, have an important role for controlling the increasing energy demand.

2.2. Natural Gas Usage and Security of Supply

Having less carbon emissions compared to other fossil fuels like coal and petrol, the importance of natural gas amongst the primary energy resources is increasingly becoming firmer. In addition to conventional reserves, the increasing number of discoveries being made for unconventional reserves with enhancement of technology does not eliminate the fact that natural gas is a fossil fuel and that like other fossil fuels their regeneration times underground are measured in millions of years. Due to the fact that the reserves of natural gas, which has a variety of uses and is quite widespread, around the World, is being condensed in basins located in certain country territories, it is being predicted that the supply security will continue to be a hot topic in energy market.

It is stated that for each three scenarios mentioned previously, the only fossil fuel that has an increase in global demand is natural gas[14]. By year 2012, according to the new policies scenario, it is predicted that the demand for natural gas, which has been 3.4 trillion cubic meters (tmc) since 2012, will rise to approximately 5 trillion cubic meters by 2035. The fact that the proven conventional and unconventional natural gas reserves have the potential to meet the increased demand is emphasized on in the Report. In addition to this, predictions for 2035 show that half of the natural gas supply will be supplied from China, USA, and Australia from unconventional natural gas reserves and in the analysis it is stated that it should be evaluated that the amount, quality and environmental impacts are uncertain[15].

On the other hand the prediction that the available reserves are able to meet the increasing natural gas demand, provides no solution for foreign dependency of countries, which import natural gas. In this regard, it is remarkable that the objectives for 2020, which are going to be analyzed in the following sections, for European Union countries with high industrial and household consumptions, in addition to sustainability and reduction in greenhouse gas emissions, are about providing security for energy supply[16]. The European Union 2020 Energy Objectives knows as the “20-20-20 Objectives” are summarized as[17]:

a) By means of increasing energy efficiency, providing 20% energy saving compared to the predictions of 2020
b) Increasing the percentage of renewable energy in the total energy consumption by 20% by the year 2020, and therefore, nearly tripling the current renewable energy percentage.
c) Reducing the greenhouse gas emissions by at least 20% in 2020 compared to the values of 1990.

[14] IEA, “World Energy Outlook 2012 - (WOE)”, *2012*
[15] Ibid p. 125
[16] European Commission, “Energy roadmap 2050”, Publications Office of the European Union, Luxembourg, 2012, p. 11-14
[17] European Commission, “Key Figures, Market Observatory for Energy”, Directorate General for Energy, June 2011, p. 25-32

Besides the emphasis on *energy efficiency* found in the 20-20-20 Targets, which also involve the critical importance of the European Union energy policies, with the *Action Plan for Energy Efficiency*, *Green Paper on Energy Efficiency*, *EU Energy Efficiency Plan* and *Towards a European Strategic Energy Technology Plan*, in addition to being evaluated in a many sided manner, is also examined in terms of supply security[18].

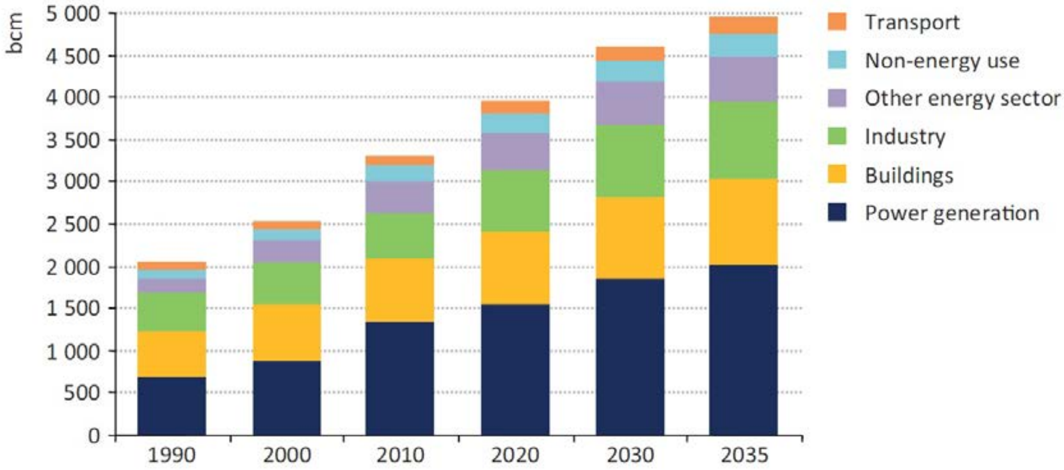


Figure 2.7. World natural gas demand by sector in the New Policies Scenario (WEO, 2012)

On the other hand, electricity generation and residential consumption can be evaluated as the two most important aspects in keeping the natural gas demand under control. In addition, being known that the natural gas sourced electricity generation power plants compose a significantly important agenda item in the World's and Turkey's energy market, it is apparent that, when the sequential data spread between 1990 and 2012 are examined, statistically, residential buildings are the second largest consumers for natural gas[19]. When the world natural gas demand estimations are examined based on sectors according to new policy scenarios, it is observed that

[18] Türkes M, G. Kılıç, "European Union Policies and Measures on Climate Change", Çevre, Bilim ve Teknoloji, Teknik Dergi, 2004, 2: 35-52.
[19] IEA, "World Energy Outlook 2012 - (WOE)", *2012*

there are no expectations for changes in this situation (Figure 2.7). In this regard, it can be evaluated that energy efficiency studies for residential buildings with natural gas, when considered with the perspectives from house economy to country economies and even sustainability, in order to leave World reserves to the next generations, are of the utmost importance on a global scale.

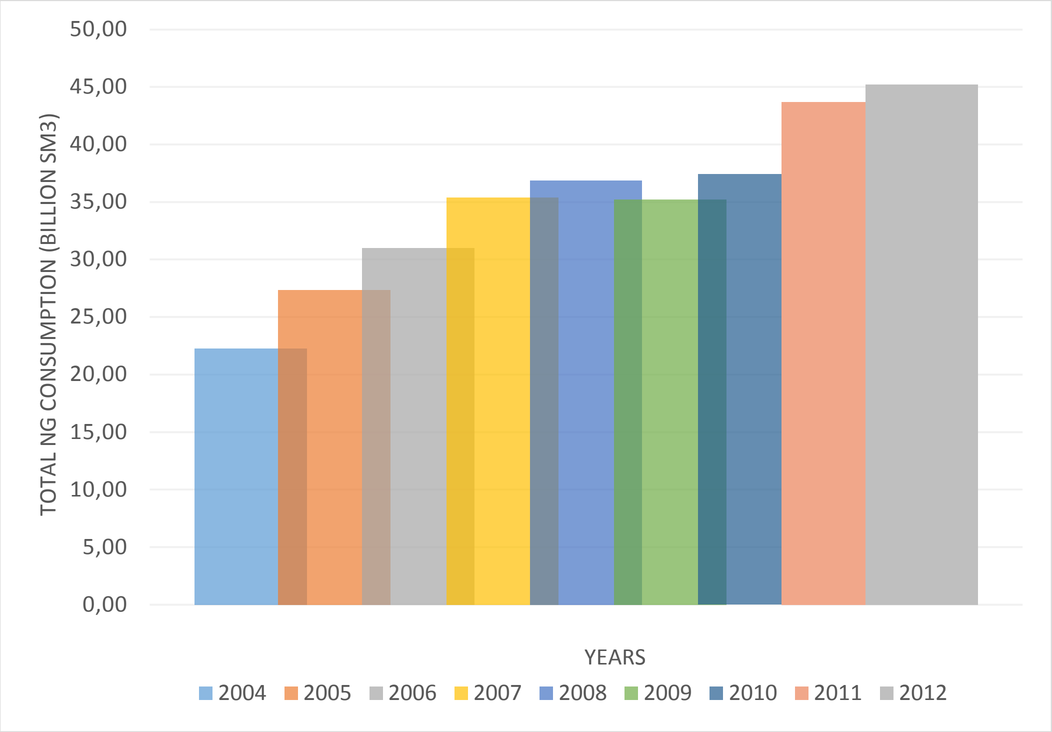


Figure 2.8. Total natural gas consumption of Turkey by years (EMRA, 2012)

It is apparent that the subject of supply security for Turkey, which has increased and diversified natural gas consumption areas after the investments made in the recent years, is considerably important. When the year of 2003, during which the EMRA realized the tenders for local natural gas distributions, is taken as reference, according to the years it can be seen that there is a tendency towards an increase in natural gas consumption. In Figure 2.8, that is based on the 2012 Natural Gas Market Sector Report published by the Head of the Department of Natural Gas, it can be observed that between the years 2004 and 2012, except the year 2009, there is always a certain increase in natural gas consumption compared to the preceding year[20].

On the other hand, it can be seen that there is no increase of natural gas production in proportion to the increase in the natural gas consumption in Turkey. The fact that domestic resources are limited is continuously a matter in both natural gas in specific and the supply security in general. The Turkish Petroleum Corporation (TPAO)'s data in the *Crude Oil and Natural Gas Sector Report of 2011* show the focus given to the subject in this regard. In Figure 2.9 it can be clearly observed that between the years of 2002 and 2011, the production of natural gas in Turkey has been low compared to consumption and that there has not been a steady increase in the production[21].

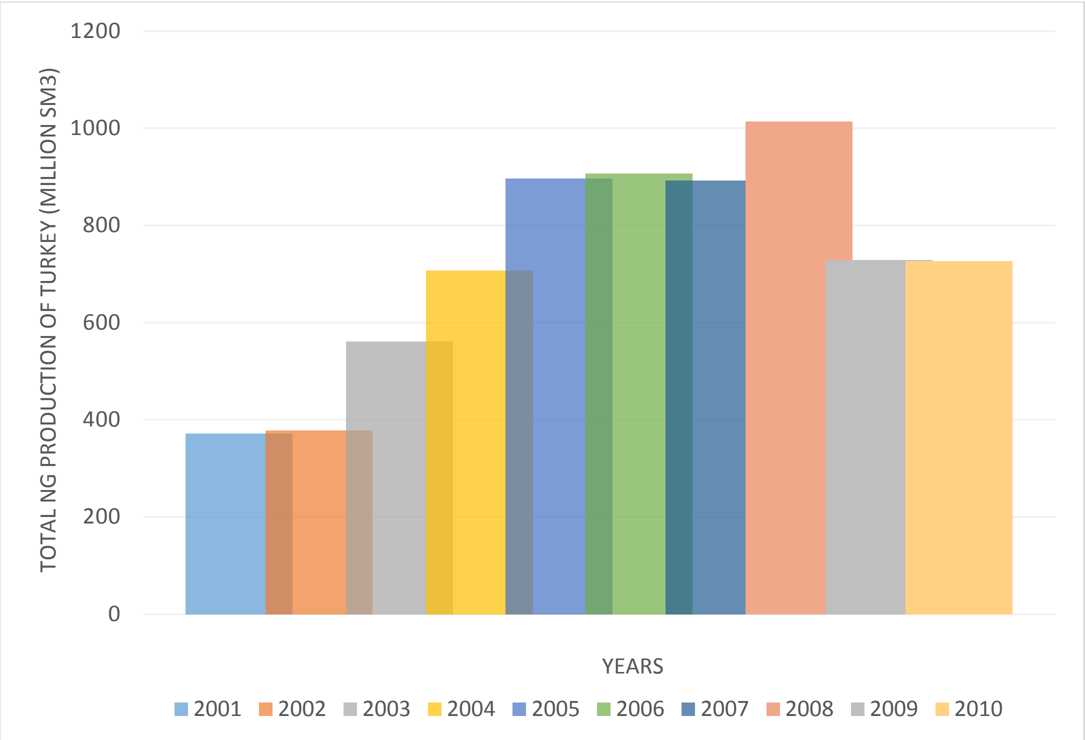


Figure 2.9. Total natural gas production of Turkey by years (TPAO, 2012)

[20] EMRA, "Doğalgaz Piyasası 2012 yılı Sektör Raporu", Ankara, 2013
[21] TPAO, "2011 yılı Hampetrol ve Doğal Gaz Sektör Raporu", Ankara, Mayıs 2012, p. 13-14

Due to domestic resources being limited, the increase in demand for natural gas is forcing Turkey to import natural gas, and the increase in the difference between production of natural gas and the amount of it being imported each year indicates a need for development of new policies for the matter of the security of supply. According to the mentioned TPAO Report, the domestic generation values in Figure 2.9 are thought to be only 2% of the imported natural gas values indicated in Figure 2.10[22]. The subject of importing can be evaluated to be important in financial terms when considering its place in current deficit figures in addition to the security of supply.

When current natural gas consumption sectors are taken as a basis, it is apparent that natural gas distribution sector appears to be following next to electricity generation. According to the data given by the Petroleum Pipeline Corporation (BOTAŞ), which is responsible for national distribution network and is identified as a public corporation, during the year 2010, there has been a sale of 30.9 billion standard cubic meters (Sm^3) of natural gas. Out of this amount approximately 2% has been exported to Greece while 18% was used in the industrial sector, 21% in residential buildings and nearly 59% in the electricity sector[23].

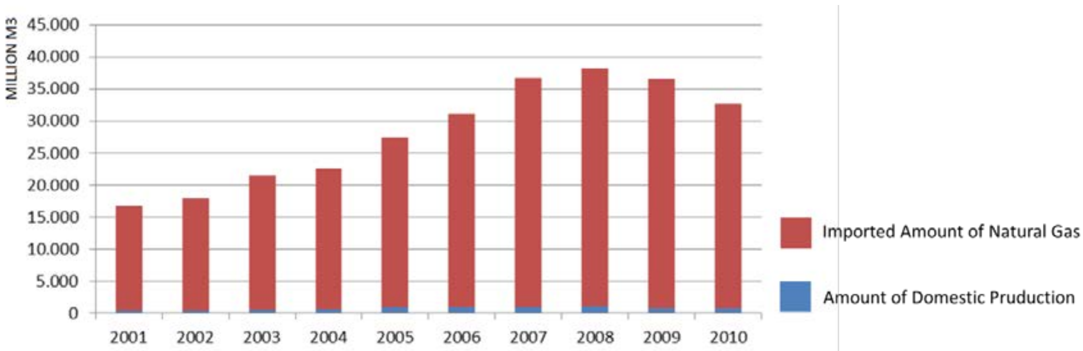


Figure 2.10. Total natural gas supply of Turkey by years (TPAO, 2012)

[22] Ibid
[23] Boru Hatları İle Petrol Taşıma Anonim Şirketi, “2010 Yılı Sektör Raporu”, Bilkent, Ankara, 2011

On the other hand, according to the data in Natural Gas Market Sector Report of 2013 published by Head of the Department of Natural Gas of EMRA, when considering all natural gas distribution regions as of the end of 2012 in Turkey, it is mentioned that the number of subscribers in 65 provinces has reached 9,171,624 of which 95% is comprised of residential subscribers[24]. It is apparent that the demand for natural gas in Turkey is directly related to residential units utilizing natural gas. It is evaluated that the applications for energy efficiency in residences with natural gas will provide valuable benefits in regards to the security of supply.

2.3. Earth System Sciences Perspective and Carbon Mitigations

The subject of environmental impacts of economic development has been increasingly occupying the World agenda since the late 1970s and such impacts will keep on being the focus of the climate change debate in the upcoming years. Climate change, as a result of the increasing concentration of greenhouse gases in the atmosphere, is manifested as a tendency towards atmospheric temperature increases due to increased amounts of energy being trapped by stable molecule bonds[25]. When the weather phenomenon occurring in the atmosphere are evaluated as mid-term and long term, they are named as the “climate” and therefore, the data related to the climate are required to be based on a time frame of at least 30 years[26]. In this regard when climate change related studies are taken into consideration, it can be seen that the subject is evaluated with historical data and is given shape according period cycles that is provided by these data. Climate predictions based on emerging consistent indications that stem from either paleontological data or astronomical observations or historical records provide a basis for studies related to studies for climate change. In this framework, the main reasons for climate change include

[24] T.C. Enerji Piyasası Düzenleme Kurumu Doğal Gaz Piyasası Dairesi Başkanlığı, “Doğalgaz Piyasası 2012 yılı Sektör Raporu”, ANKARA, 2013
[25] Thomas H. Tietenberg, “Environmental & Natural Resource Economics - 9th Edition”, Pearson Education, Inc., New Jersey, 2009-2012, p. 3-4
[26] David Huddart, T. Stot, “Earth Environments: Past, Present, and Future”, by John Wiley & Sons Ltd. West Sussex, 2010, p. 89-100

climatic changes related to a) solar effects, b) World's orbit and axis, c) volcanic activities, d) oceanic and sea effects and e) anthropogenic effects[27].

Climate changes occurring due to differences in solar effects where insolation times and the amount of solar energy falling on the Earth's surface show differences have been stated in historical sources from 2000's B.C. sourced from China and Mesopotamia[28]. It is known that during times when there is an increase in sunspots which occur on the Sun's surface resulting from activities due to magnetic fields, there is an increase in the effects of the sun and the World goes through hot and arid periods and when there is a decrease in these sun spots, temperature decreases that can lead to small sized ice ages can occur[29].

On the other hand, periodic changes on an astronomical scale that occurs due to the World's orbit and axis while rotating around the Sun result in changes in the amount of the Sun's energy falling on the Earth's surface which in turn results in climate changes. These cycles that record the climate changes resulting from insolation are known as the Milankovitch Cycles. The Milankovitch Cycles present a considerably characteristic and repeating sequence in periods of 21,000 years, 41,000 years and 100,000-400,000 years[30].

Another climate change parameter is the climatic changes developing due to volcanic activities. Unlike outside effects like the Sun's movement and orbit-axis effects, volcanic activities are considered as an internal climate change cause. One of the main volcanic phenomenon are the ashes that remain suspended in the air and the SO_2 emissions cause effects to the atmosphere that results in cooling effects. Additionally, in cases where the amount of volcanic ashes suspended in the air is very dense, cloud effects occur which result in the reflection of the Sun's rays away

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[27] Ibid, p. 761-764

[28] K. Arora et al. "Correlations Between Sunspot Numbers, Interplanetary Parameters and Geomagnetic Trends Over Solarcycles 21-23", Journal of Atmospheric and Solar-Terrestrial Physics 114, 2014, p. 19-29

[29] S. Mufti, G.N. Shah, "Solar-Geomagnetic Activity Influence on Earth's Climate", Journal of Atmospheric and Solar-Terrestrial Physics 73, 2011, p.1607–1615

[30] G. A. Florides et al. "Reviewing the Effect of CO_2 And the Sun on Global Climate", Renewable and Sustainable Energy Reviews 26, 2013, p. 639–651

from the Earth's atmosphere, which in turn, with this positive feedback, intensifies the already occurring cooling effects[31].

Another climate change determinant that can be classified as an internal cause is the hot water effects brought by ocean waves to the shores. For example, the "Gulf Stream" is part of the North Atlantic Stream and is fed by the North Equator Stream and finally by the Great Belt. It is known that this stream is what provides a habitable climate for northern Europe by at tempering it[32].

In addition to the above-mentioned natural causes of climate change, another cause that will be discussed below is the climatic changes that are brought about by human actions. Anthropogenic causes of climate change are generally two-fold. First of all, local climatic changes may occur due to land use and land cover change, which are usually related to the human impacts on forests or dams with wide reserves that create big and artificial water pools[33]. The second human impact occurs in terms of greenhouse effects that originate from increasing use of fossil fuels. This second form of human impact on climate change makes energy efficiency an important policy goal for the World's nations.

When the above-mentioned causes of climate change are considered, the impact of greenhouse gas emissions on Earth's climatic conditions may be deemed unimportant at a glance; however, the scientific studies indicate the opposite of this view. When the cycles that occur due to solar activities and orbit-axis changes are evaluated together with the temperature graphs provided by geological data, it becomes possible to make scientific predictions for the near future. When the natural cycle data are taken into consideration, it is seen that the World should be entering into a cooling phase instead of how it appears to be drifting towards a warming

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[31] H. Meronen et al. "Climate Effects of Northern Hemisphere Volcanic Eruptions in an Earth System Model", Atmospheric Research 114–115, 2012, p. 107–118
[32] S. E. Jorgensen, "Global Ecology", Elsevier Science & Technology, April, 2010, B. 13, p. 1923-1930
[33] F. Evrendilek et al. "Historical Spatiotemporal Analysis of Land-Use/Land-Cover Changes and Carbon Budget in a Temperate Peatland (Turkey) Using Remotely Sensed Data", Applied Geography 31, 2011, p. 1166-1172

atmosphere. This contradiction to expectations may be occurring due to the greenhouse effects[34]. The Fifth Assessment Report of the Intergovernmental Panel on Climate Change[35] (IPCC-AR5) emphasizes the fact that anthropogenic GHG concentration results in climate change[36].

The anthropogenic greenhouse gas emissions have increased since the industrial revolution, especially during the mid-20th century when fossil fuel consumption became widespread. During the last two decades, on the other hand, discussions regarding the mitigation of GHG emissions have begun to be emphasized in both academic literature and policy debates. In academic studies, greenhouse effects are mentioned in a variety of measurements. In addition to this, calculations made in this research are based on evaluations including million tons of CO_2 equivalent (Mte CO_2) or a single unit part per million particles in the atmosphere (ppm). Figure 2.11 indicates the increase in CO_2 concentration in the atmosphere in terms of a single unit part in one million particles (ppm) in the atmosphere since 1950.

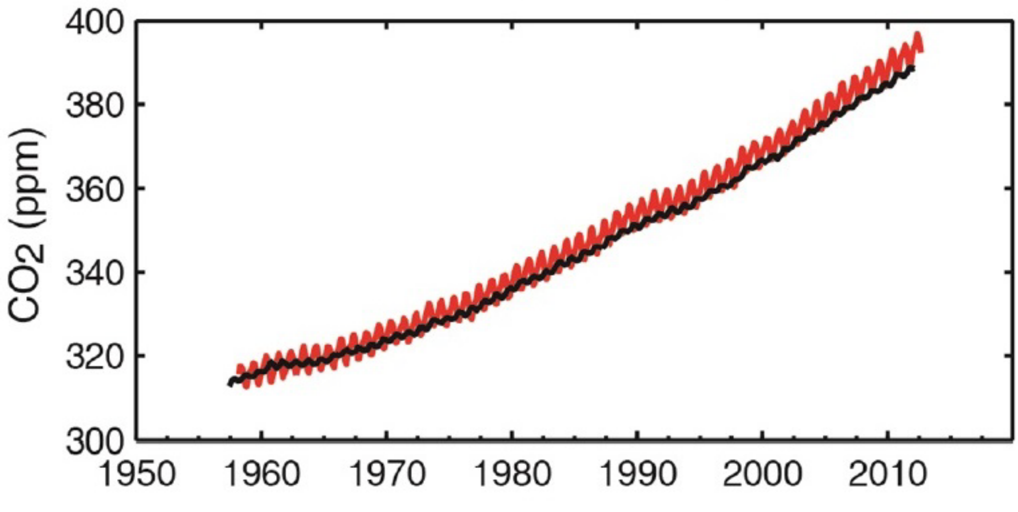

Figure 2.11. Total amount of CO_2 in the Atmosphere by years (IPCC-AR5, 2013)

34 D. Owen and Nick Hanley, "The Economics of Climate Change", Routledge, London, New York, 2004, p. 27-55

35 IPCC is an international organization with the strongest influence over climate change debate and performs activities under the roof of the United Nations.

36 IPCC, AR5, "Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change", Cambridge University Press, Cambridge, and New York, 2013, p. 659-741, 677.

According to the IEA 2013 data, the value of 15,628 million tons of CO_2 equivalent across the World in 1973 were doubled and increased to 31,342 million tons of CO_2 equivalent in 2011[37] (Figure 2.12.).

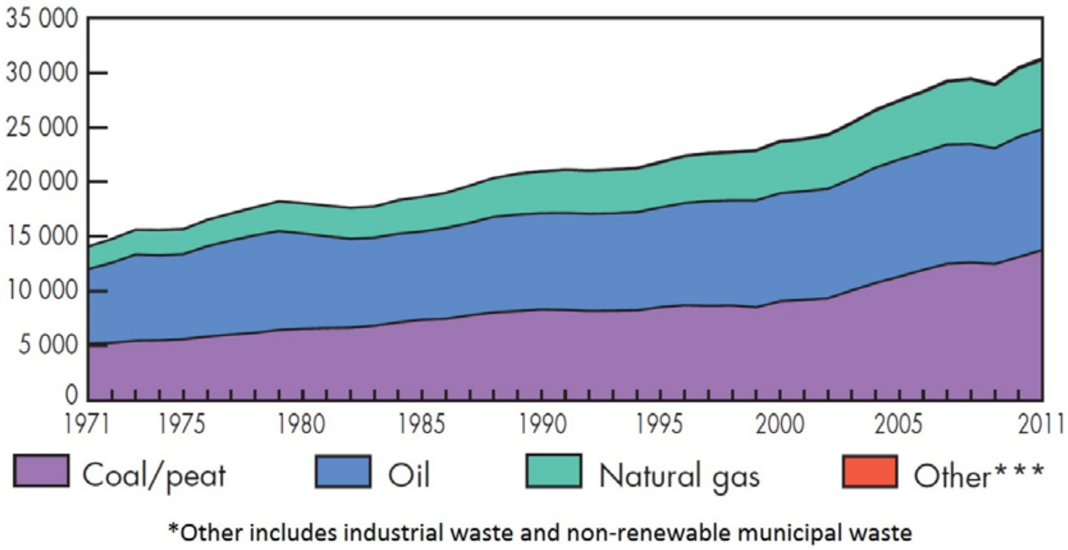

Figure 2.12. World CO_2 emissions by years by fuel in terms of Mt of CO_2 (IEA, 2013)

Natural gas, which produces lesser amounts of CO_2 per unit consumption compared to other fossil fuels, due to its chemical structure, cannot be evaluated as an alternative to fossil fuels. Although it has advantages in terms of alternative CO_2 cost reductions, it is observed that the increase in utilization of natural gas resulted in increased effects in terms of greenhouse gas emissions. In 1972, while 14.4% of the total CO_2 production was from natural gas, in 2011 this figure was increased to 20.2%[38]. In other words, natural gas, which had an emission of 2,250.43 million tons of CO_2 equivalent across the globe in 1973, produced a total of 6,331.08 million tons of CO_2 equivalent in 2011, indicating nearly threefold increase between 1973 and 2011.

[37] IEA, "Key World Energy Statistics 2013", 2013, p. 44-45
[38] Ibid p. 44

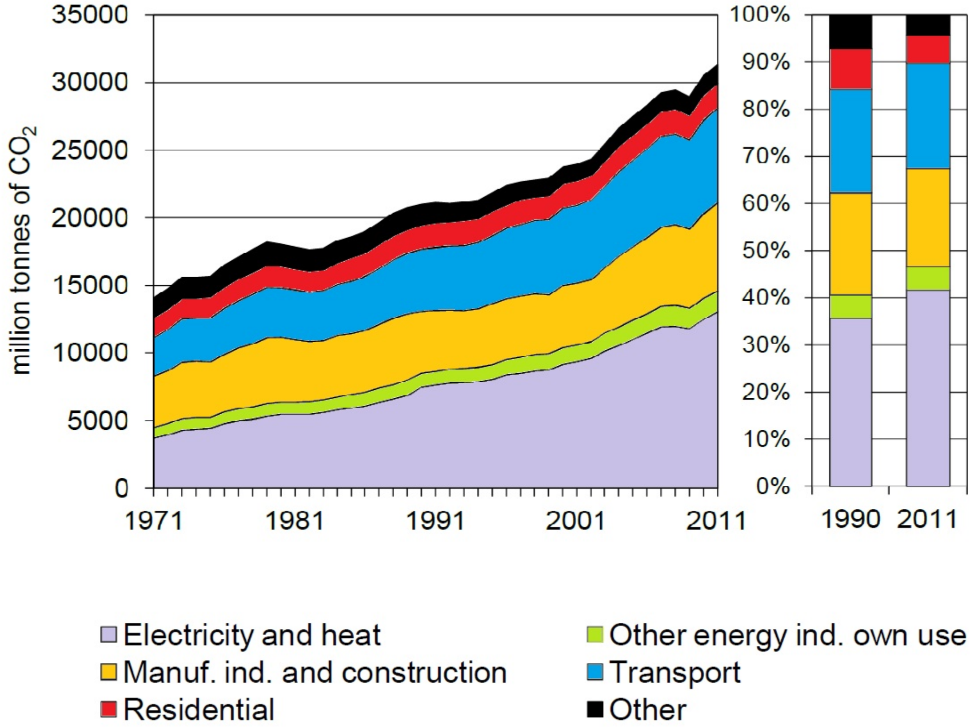

Figure 2.13. World CO_2 emissions by sectors (IEA, 2013)

Most of the human actions that cause current GHG concentration in the atmosphere and thereby global warming are related to cities. Urban development is regarded as a substantial part of the climate problem due to high energy consumption in key urban sectors[39]. The residential sector in cities is one of major urban sectors, where high energy consumption contributes significantly to the climate problem. GHG emissions produced by the residential sector are mainly the result of the energy consumed for heating purposes. However, it should be emphasized that the entire CO_2 emissions that stem from residential sector are not only based on natural gas usage. Based on the detailed statistics provided in the report titled "CO_2 Emissions From Fuel Combustion Highlights", which was published by the International Energy Agency in 2013, GHG emissions by sectors between 1971 and 2011 are indicated in Figure 2.13. Likewise, the CO_2 emissions shares of sectors and the

[39] O. Balaban, "Climate Change and Cities: A Review on the Impacts and Policy Responses", METU Journal of the Faculty of Architecture, 29 (1), 2012.

changes in the shares can be found in total emission comparisons referenced for the years between 1990 and 2011 according to the Kyoto Protocol[40].

Additionally, according to the data found in the section related to buildings in the study titled "Towards a Green Economy", published by the United Nations Environment Program (UNEP) in 2011, the predictions made by *the G2 Scenario (G2)* and the BAU Scenario (BAU) are compared. While BAU assumes that current trends would continue until 2020, the G2 scenario discusses the possible outcome in case 2% of the global Gross National Product is spent on ten different sectors for green economy policies while giving importance to the building sector based on increasing investments for green buildings and improving current building structures. In this regard, in Figure 2.14 and Figure 2.15, the energy demands in buildings across the globe and the associated CO_2 emissions can be seen for each of the two scenarios[41]. Figures clearly indicate the potential embedded in buildings sector for mitigating energy use and thus CO_2 emissions.

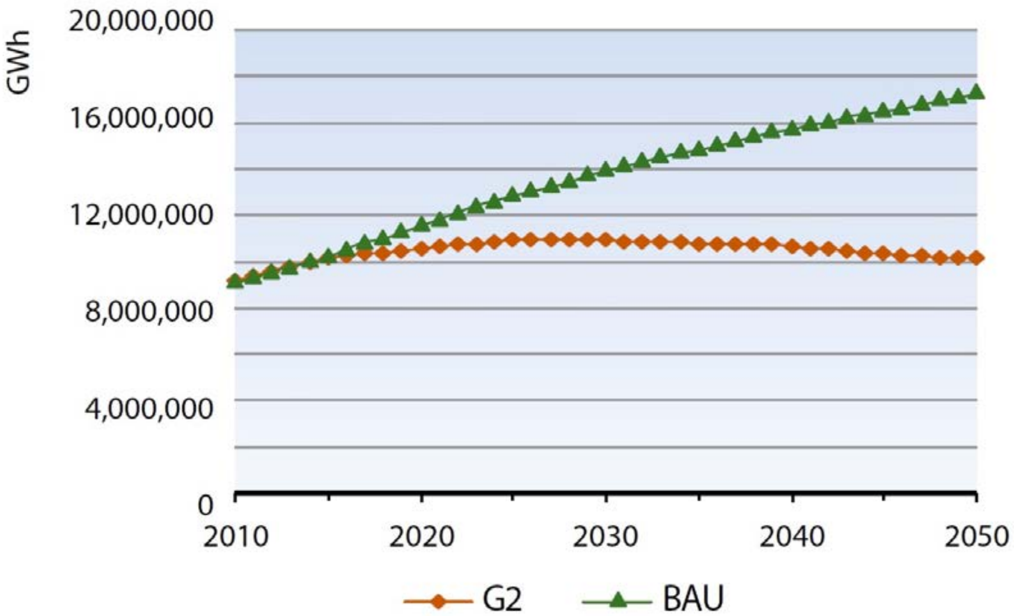

Figure 2.14. Total energy demand per year in buildings sector

[40] IEA, "CO_2 Emissions From Fuel Combustion, Highlights", Paris, 2013 p. 132
[41] UNEP, "Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication", 2011, p. 331-371

2010-2050 (UNEP, 2011)

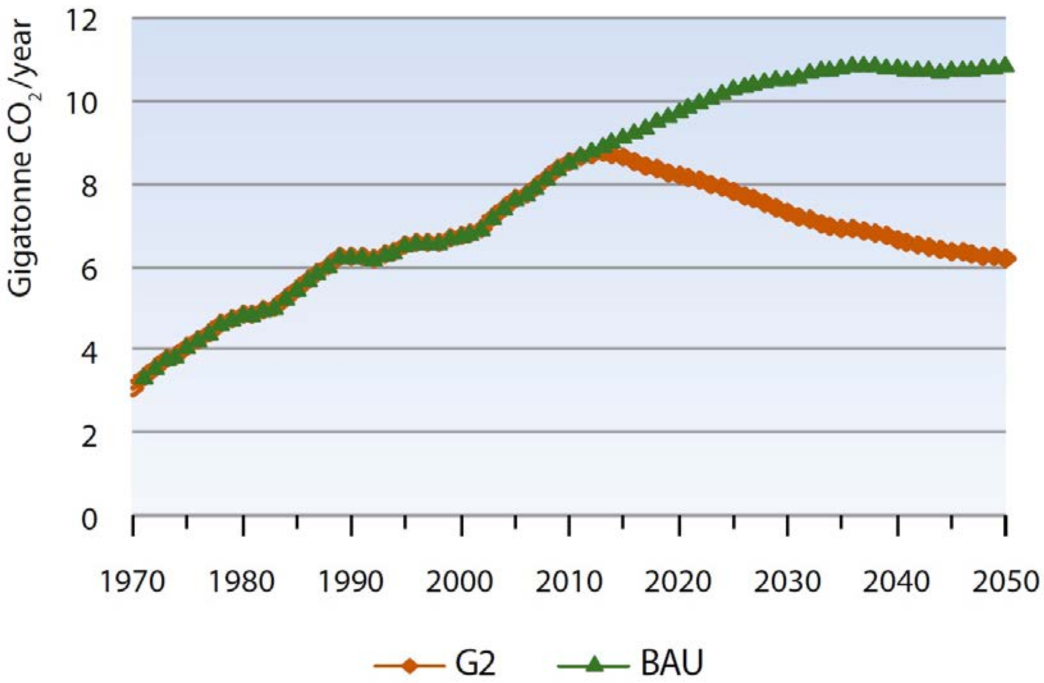

Figure 2.15. Total CO_2 emissions per year in buildings sector 2010-2050 (UNEP, 2011)

When CO_2 emissions related to natural gas use in Turkey are examined, it is seen that there has been a significant increase since the 1980s, when natural gas usage was initialized. The graph created according to CO_2 Emissions From Fuel Combustion report of IEA, provides an indication of the natural gas related CO_2 emissions by years (Figure 2.16). In 1985, the amount of 0.1 Million ton of CO_2 equivalent emissions in Turkey was; 6.5 Mt in 1990, 13 Mt in 1995, 28.9 Mt in 2000, 52.8 Mt in 2005, 67.4 Mt in 2009, 73.2 Mt in 2010 and 85.7 Million ton of CO_2 equivalent in 2011 and as seen in Figure 2.16, it can be observed that there is a tendency towards an increase[42].

[42] IEA, "CO2 Emissions From Fuel Combustion, Highlights", Paris, 2013 p. 59

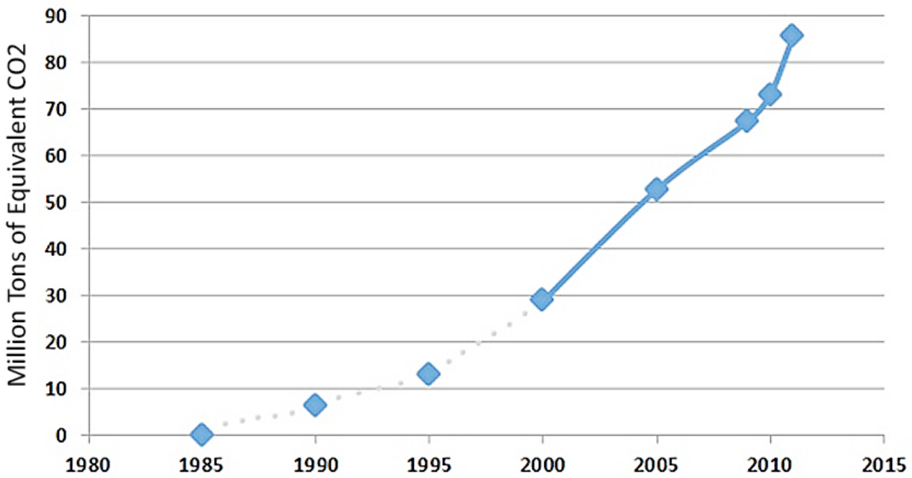

Figure 2.16. Turkey's CO_2 emissions related natural gas consumption (IEA, 2013)

When CO_2 emissions by sectors in Turkey are taken into consideration, likewise the World trends, a clear calculation towards determining residential heating systems cannot be made. Coupled with this fact, Table 2.2 is made by using the 2011 data for mtoe CO_2 eq emissions by sectors in Turkey, provided by the "Fuel Related CO_2 Emissions Report", which was published in 2013 by the International Energy Agency. Based on this data it seems possible to make an estimation of greenhouse gas emissions for 1 year for residential and domestic energy consumptions[43].

Table 2.2. Turkey's CO_2 Emissions Based on Sectors for 2011 (IEA, 2013)

Sectors	Emissions in Million Tons of CO_2 Equivalent
Fuel Based Total CO_2 Emission	285,7
Electricity and Heat Generation	111,4
Other Energy Industries Besides Electricity	9,9
Manufacturing and Construction Industry	53,9
Transportation	85,3
Residential and Domestic	43,5
Other	64,9

[43] Ibid p. 71

In the light of this data, it can be concluded that improving the energy efficiency of current available systems will reduce GHG emissions and thereby address climate change. It is observed that making Turkey's residential stock energy efficient will be important in mitigating both CO_2 and methane (CH_4) emissions.

Although it is a type of fossil-based fuels, natural gas, due to its inherent advantages, is considered less polluting compared to other fossil fuels. Turkey's reserves for natural gas is very limited and most, if not all, of the natural gas consumed are imported. Therefore, ensuring energy efficiency, especially in domestic heating systems where natural gas is commonly used and in applications that use natural gas in general, is important not only for energy demand management but also for policies to address climate change.

CHAPTER 3

METHODOLOGY AND FIELD RESEARCH

This research aims to develop a methodology to compare the energy (natural gas) consumption levels of three residential heating systems that prevail in most of the residential blocks in Turkey. These heating systems are a) stand-alone heating systems (individual unit based), b) central heating systems (block based) and c) district heating systems (neighborhood based). The methodology developed in this research is utilized by using actual data of residential natural gas consumption and assumed to be useful in guiding and supporting better policy-making for energy efficiency.

At the initial stages of the research, it was planned to use the database of local natural gas distribution companies. Due to easier field research opportunities and availability of a natural gas distribution company, Ankara appeared to be plausible case city for the research. However, the inadequacy of the database and data set of the distribution company in Ankara has led us to focus on another city. Considering Eskisehir, Kayseri, İstanbul and Bursa, Bursa was selected as the case city for the research conducted in this study. There are several reasons for selection of Bursa as the case city. These reasons are listed below:

- Bursa is the fourth-biggest city by population in Turkey. The city accommodates 2.688.171 people and 743.394 dwelling units according to the data obtained from the Turkish Statistical Institute (TUIK) Address Based Population

Registration System (ABPRS), particularly the 2012 Results and Population and House Research[44].

- Bursa has one of the first natural gas distribution pipeline in Turkey, which was started to be built in 1989. The first residential gas supply was provided in 1992 in Bursa (EPDK, 2014). The historical background of natural gas supply in Bursa city is considered as a significant opportunity with the perspective of both established natural gas distribution service and steady culture of final consumers of natural gas.
- While most of the natural gas distribution regions in Turkey does not include residential district heating systems (neighborhood-based systems), Bursa city has all the three heating systems: Individual Heating (IH), Central Heating (CH) and District Heating (DI) Systems. Therefore, Bursa city has the potential to serve as a basis to compare the natural gas consumption levels of three different residential heating systems.
- Energy Market Regulatory Authority (EMRA)'s licensed natural gas distribution company of Bursa (BURSAGAZ) is one of the most experienced companies in Turkey. With its 26 years of experience in natural gas distribution and 9 years of experience in SAP integrated database management, BURSAGAZ Company promised a reliable data set.

On the other hand, Bursa city had some disadvantages for empirical research along with the advantages it promised. In addition to logistical difficulties for conducting the fieldwork, Bursa city had another disadvantage for the research. Although Bursa city can be considered as a single region as per the national standard numbered TS 2164, which sets the principles for heating systems projects, the city includes mountainous, coastal and lakeside zones in close proximity. In this respect, different climatic zones could be found in Bursa and sample buildings in such different climatic zones might have adverse impacts on research results. Therefore, special attention has been paid to choose sample buildings for the case study research in close proximity and same climatic zone..

[44] TUIK, Nüfus ve Konut Araştırması, (Publishment date and number 31.01.2013-15843), 2012

After Bursa is selected as the case study city, sample buildings are determined. First of all, residential buildings that are connected to District Heating System (DH) are chosen from the database of the BURSAGAZ Company. It should be noted here that the DH system is not defined in the data set because it can be seen as an exceptional case for this field in both legacy and application perspectives. That is why buildings connected to DH system are defined as CH system category on the consumer database of the company. However with the help of other data instruments such as Geographical Information System (GIS) and the interior installation projects, there are 12 different residential buildings with DH system can be determined.

Firstly it was searched that if there was a building with DH system, which was built after 5th of December 2009, which is the enactment date of the National Directive for Energy Performance of Building. Since such a building cannot be found, the newest five DH system users were selected considering their construction date. These buildings were visited on site between 15 and 19 December 2014. Building number included in the DH system, apartment number of each building, occupancy rates of the residential buildings, total heating area, common heating areas which are not residential, building age, situations of the building envelope insulations, buildings shapes, building region, sale and rent prices for the apartments and the dwellers' profiles are noted on the Building Definition Forms for each building (Appendix A).

Selected five DH system are located in site complexes. However three of five DH systems heats not only residential areas but also common areas such as school and shopping areas. Four of five DH system user sites including building type diversity in their selves. Except one of these DH system users have over 25 blocks and 750 different apartments for each site complex. The selected DH system is S.S. Saygınkent Kooperatifi (Saygınkent), located in 100. Yıl Settlement, Prof. Dr. Erdal İnönü Street is a smaller site complex has 7 blocks with same standard building shapes, which can be easier to consider in comparison study. Saygınkent DH system has a heating center and this center feeds only residential 7 similar 18floored blocks with 476 apartments. It is also the newest buildings built in 2005, comparing with the other five DH system complexes. Another advantage of Saygınkent is its corporate identity, which is very significant to reach data in this study.

Considering the listed criteria, Saygınkent is selected as the sample site for the DH system buildings to be analyzed in this research. After the DH system building within Saygınkent is determined (Figure 3.2, the one on the left), CH system and IH system buildings are also determined by using the same criteria in order to carry out an accurate comparison. In order to minimize the effects of climatic alterations, CH and IH system building are searched for within the vicinity of the DH system building. Since the DH system building is located in 100. Yıl Neighborhood in Nilüfer District (Municipality), the search for other sample buildings was focused on this region.

Figure 3.1. Satellite image and the photograph for samples (Google, 2015)

According to the defined criteria above, five buildings are determined for each CH and IH systems. After the field visit to the selected buildings, conditions of the buildings are noted on Building Definition Forms. With the help of these inputs and BURSAGAZ database, CH system user building is selected from Altınşehir Settlement and IH building is selected from Cumhuriyet Settlement. Both buildings are located in Nilüfer District (Municipality) and also very close to the 100. Yıl Neighborhood (Figure 3.1).

The building with CH system is determined as C-Block of Mescioğlu Complex (Mescioğlu) located in Altınşehir Settlement, 257th Street, Number 12 in Nilüfer (Figure 3.2, the one in the middle). This building has 30 dwelling units in 8 floors and was built in 2012. The building with IH system is determined as Yidem Apartment (Yidem) located in Cumhuriyet Settlement, Anıt Street, Number 18 in Nilüfer (Figure 3.2, the one on the right). This building has 15 apartments in 5 floors and was built in 2000.

Figure 3.2. Photographs for samples DH, CH and IH system buildings respectively

During the first field visit, sample buildings were seen on site, selection of the buildings were finalized and related data were chosen from the database of the BURSAGAZ Company. The natural gas consumption data are recorded as consumer data according to the billing final natural gas consumption. It is important to express this procedure is implementing under the Energy Market Regulatory Authority (EMRA) legislations and regulations. The consumption amount to be taken as basis for billing is regulated by EMRA with the Annunciation for Accurate Billing Principles on Determination of Amount of the Natural Gas Consumption[45].

In this annunciation the relation between the volume of the natural gas that is read from the index of customer's meter (m^3) and the amount of energy bases for the billing is regulated. The volume definition of the annunciation is $1m^3$ equals the amount of gas under 15^oC temperature and 1,01325 bar absolute pressure. On the other hand, this regulation includes that the obligation of distribution company on the recording of its prices in the tariff in terms of both energy (kWh) and volume (m^3). Since the chemical content of the natural gas could be changed, the energy can be generated from gas combustion also changed. Standardization is needed, which is based on calorific value of the natural gas. That is why distribution companies records the volume in terms of standard cubic meter (Sm^3), which is defined as the amount of $1m^3$ natural gas with the higher heating value of 9155 kcal/m^3 without water vapor.

Natural Gas Distribution Company has a system to read metering index monthly. However if the monthly consumption amount of a consumer is less than 20 Sm^3 this data is not recorded on the database, until that amount comes greater than 20 Sm^3. This can be observed on the data especially for IH system users consumptions for the summer months. It can be said that the natural gas consumption of summer months is related with only water heating and kitchen usage. For this study, while IH, CH and DH system users consume natural gas for water heating only, IH system users consume gas for kitchen usage too. When it is considered that total share of water

[45] EMRA, Doğal Gazın Faturalandırmaya Esas Satış Miktarının Tespiti ve Faturalandırılmasına İlişkin Esaslar Hakkında Tebliğ, Official Gazzette with the date and number 31.12.2002-24980

heating and kitchen is 5% of the total residential natural gas consumption in Bursa[46], amount of natural gas consumption for water heating is neglected in the sample building with IH system.

The consumption data of these three buildings are re-organized after the first field research. For the building with IH system, each of the15 dwellings has its own meter for natural gas consumption, while the building with CH system has a single meter for 30 dwellings and the buildings with DH system have a single meter for 7 blocks with 476 dwellings. Monthly consumptions for 2014 are listed. Total consumption is calculated annually in terms of natural gas volume (Sm^3), which can be seen on Appendix B.

For the second stage of the research, combustion efficiencies of boilers were needed in order to better calculate CO_2 emissions. Besides, building envelope insulation materials had to be defined to carry out a reliable comparison between sample buildings and heating areas were required to resolve for calculations of natural gas consumption and CO_2 emission per unit area.

The second field research was realized between 16 and 19 February 2014. This time, combustion efficiencies of the boilers were determined on site. The brand and the model of each 15 kombi boilers was noted for the building uses IH system. Each of these boilers has 20.000 kCal/h capacities as it can be commonly seen on the market. In CH system, 3 identical wall-type kombi boilers with 98.882 kCal/h capacity were used and for the DH system was found to use three different boilers with 3.569.000 kCal/h, 3.612.000 kCal/h and 4.472.000 kCal/h capacities.

These boilers seen on site were matched on the catalogs of the producer firms to determine the combustion efficiencies. Although some of the efficiencies of some boilers can be seen as more than 100% on the catalogs of the firms, these values were considered as the overall of combustion efficiencies and condensation savings.

[46] Öz, M. Konutlarda Enerji Kullanım Eğilimleri Ve Tüketimin Çevre Faktörleri İle İlişkisi, Bursa Örneği, X. Ulusal Tesisat Mühendisliği Kongresi, İzmir, 2011

For these boilers combustion efficiencies were taken into calculations without condensation saving. This is because CO_2 emissions of the condensation process of boilers can be neglected for this research.

During the second field research, building materials that were needed to calculate overall wall heat transfer coefficients (U-values) according to the TS 825 were also defined. Each layer included to the calculation was defined. In case the construction project that included the material data could be reached, the project was used to determine the layers on TS 825. However, in case of lack of detailed information about construction materials defined in TS 825, it was asked to the building dwellers to find out the missing information.

Another significant issue that should be well defined for this research is heating areas. Different approaches and legislations can be found for area calculations both in construction and heating literature. Although in Building Energy Performance Directive of the Ministry of Environment and Urbanization, area criteria are attached with the specified area on construction permits, in this research area definition was based natural gas distribution legislations of EMRA. However, there are two different area definitions that can be found in natural gas distribution literature. One of them is the Number of Detached Section (BBS) definition that is used for subscription process and related to tariff[47]. According to this regulation, there are different intervals defined for BBS calculations. If the net area of the house is less and equal to 200 m^2 this area considered as 1 BBS and every each additional 100 m^2 consider brings one more BBS for the consumer. The second definition comes from the interior installation based area. This is included in the calculations heating capacity of the space. That is why interior installation based areas are selected in this methodology for comparison of natural gas consumptions of the sample buildings.

However, interior installation projects are designed by smaller firms that are certificated by the natural gas distribution company. Furthermore each project should be approved by the natural gas distribution company. Although it is an important

[47] EMRA, Board Desicion with the date and number 28/12/2011-3603

part of the distribution activity because of the lack of detailed regulation, and the difficulties related with huge number of projects, shortage of time in approval schedule and some technical details that are considered more important than data recording these project databases are not recorded as regularly as BSS datum of consumers. Most of them are archived and only in case a project is needed it can be found in most of the distribution companies. For the following parts of the methodology, this issue will be handled to consider the citywide housing stock area data so as to find out the potential emission reductions in case different projections of widespread use of IH, CH and DH systems as a base for policy making.

At the end of the second field research, the calculations and comparison have been initiated. In order to compare the different types of buildings, each building has to be configured as per the reference building with proportional adjustments.

According to the TS 2164, outer air temperature should be used in design is -6°C for Bursa. In this study, outer air temperature is selected, -6°C for sample buildings. Therefore, only U, A and T_i parameters be adjusted proportionally[48].

Another required adjustment is related with the height of buildings according to the TS 2164. There is higher wind speed around the high floors, thus heat transfer around the high floors is higher than lower floors. In the standard augmentation proportions for high floors was specified.

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[48] Evren, M. F., Melez HVAC Sistemlerinde En Uygun Işınım-Taşınım Oranının Deneysel Olarak İncelenmesi, M.Sc. Thesis, Gazi University, Graduate School of Natural and Applied Sciences, Ankara, 2015

CHAPTER 4

CALCULATIONS AND PROJECTIONS

According to the methodology discussed in previous chapter in detail, calculations are executed for the selected sample buildings. TS 825 and TS 2164 are the main standards used for augmentations and adjustments that can be seen under the first title of this chapter. With the results of the calculations, there are citywide cases projected to be able to see the total effects of heating systems. The second part of this chapter includes the results for total residential natural gas consumption and related carbon emissions for Bursa for these projected cases.

4.1. Calculations, Augmentations and Adjustments

Equation-1 shows that the relationship between sensible heating/cooling load, q, and space air temperature, T_i, outer air temperature, T_o, overall heat transfer coefficient of walls, U. According to the Equation 1, parameters affect the building energy consumption, are insulation, exterior wall area, interior air temperature and outer air temperature.

$$q = UA(T_i - T_o) \tag{1}$$

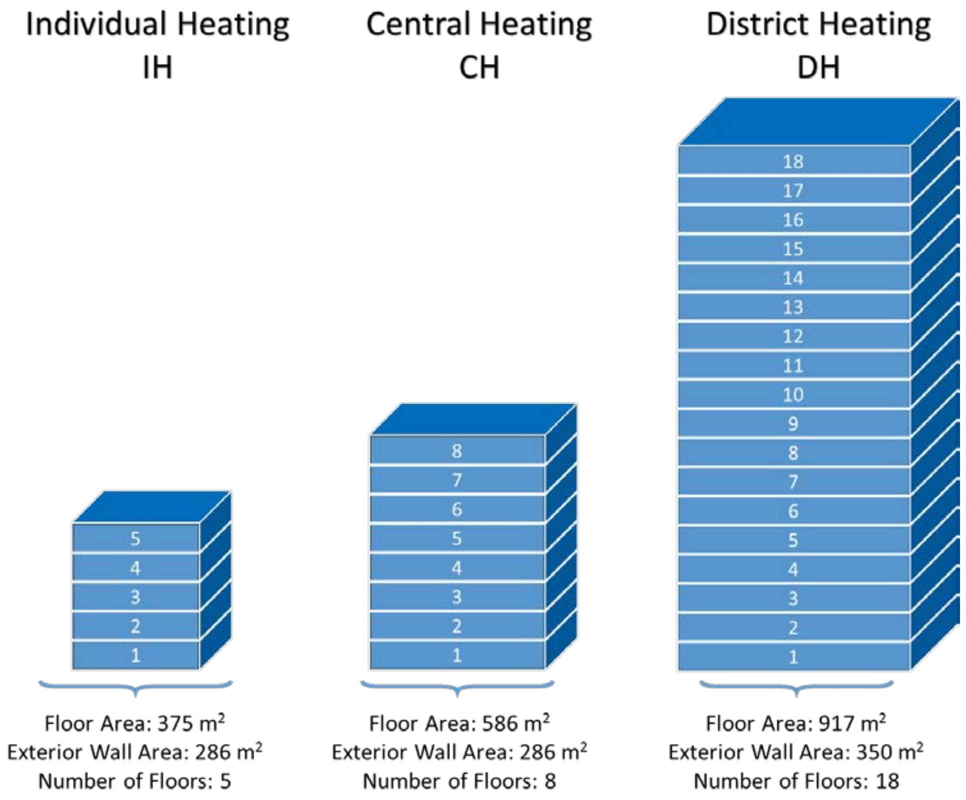

Figure 4.1. Areas and number of floors for sample buildings

According to the Standard numbered TS 2164, outer air temperature should be used in design is -6°C for Bursa. In this study, outer air temperature is selected, -6°C with respect to the Standard TS 2164 and this value is equal for three buildings. Therefore, only U, A and T_i parameters should be adjusted proportionally.

Another required adjustment is related with the height of buildings. There is higher wind speed around the high floors, thus heat transfer around the high floors is higher than lower floors. In the standard augmentation proportions for high floors was specified as presented in Table 4.1.

According to TS 2164 there is another required adjustment related to the orientation of buildings. While buildings with IH and CH system are oriented in same South-North directions, building with DH system is oriented in Southwest-Northeast.

However in this research, each of sample buildings is considered as a single volume. That is why orientation adjustments are not required for the comparison case.

Table 4.1. Augmentation for High Floors (Z_w) (TS 2164)

Total Number of Floors												Z_w (%)
4	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	
3.2.1	3.2.1	3.2.1	3.2.1	3.2.1	3.2.1	3.2.1	3.2.1	3.2.1	3.2.1	4.3.2.1	5.4.3.2.1	**0**
4	4	5.4	5.4	5.4	6.5.4	6.5.4	6.5.4	6.5.4	6.5.4	7.6.5	8.7.6	**5**
	5	6	6	7.6	8.7	9.8.7	9.8.7	9.8.7	9.8.7	10.9.8	11.10.9	**10**
			7	8	9	10	10	11.10	12.11.10	13.12.11	14.13.12	**15**
							11	12	13	14	15	**20**

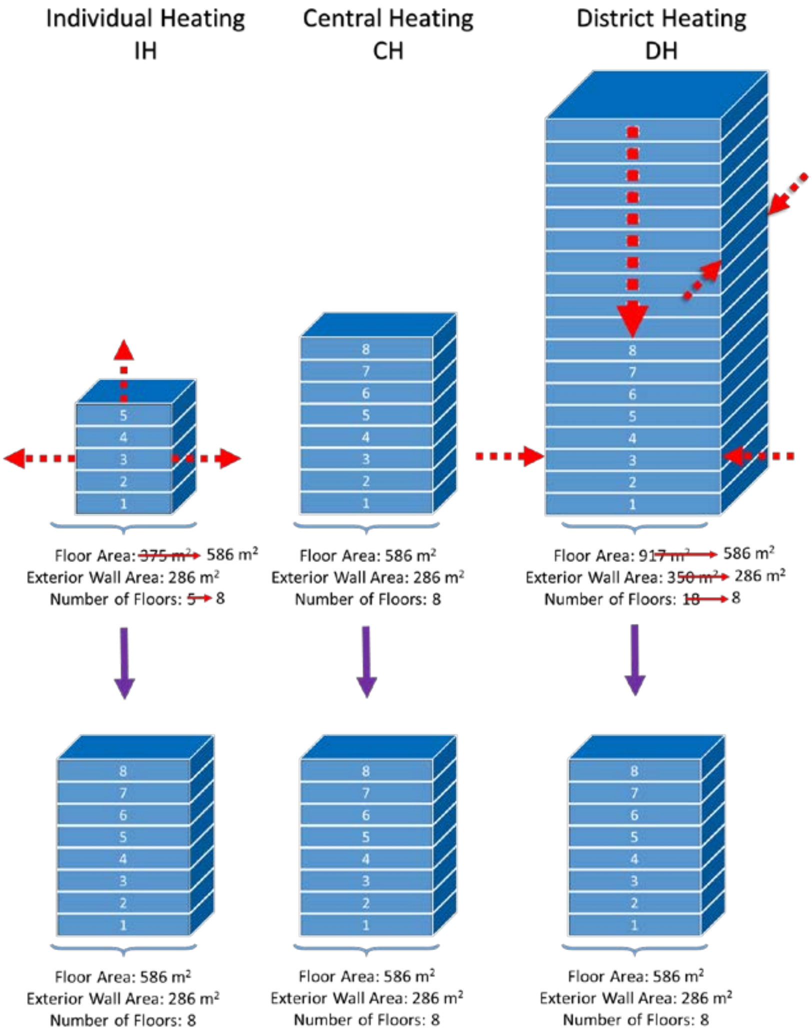

Figure 4.2. Augmentations and adjustments for sample buildings

There are 7 Steps for augmentation and the adjustments are presented below:

Step 1) Natural gas consumption for ground floor is calculated to be able to calculate the heating loads of rest of the floors

Since natural gas consumption is proportional with the heating load, Equation 1 have been considered as shown in Equation 2.

$$NG \propto q = UA(T_i - T_o) \tag{2}$$

Building total energy consumption, q, can be determined by summation of energy consumption of each floor (Equation 3). Here, j represents the floor number.

$$NG \propto q = \sum q_j \tag{3}$$

Equation 3 can be rewritten as in the form of Equation 4, here building total natural gas consumption, NG_T, is equal to summation of natural gas consumptions of each floor, NG_j. Here unit of the NG is Sm^3.

$$NG_T = \sum NG_j = NG_1 + NG_2 + NG_3 + NG_4 + NG_5 + \cdots + NG_j \qquad (4)$$

Equation 4 is applied for sample IH as in Equation 5, here subscript j-IH represents the j^{th} floor of the sample IH.

$$NG_{T-IH} = \sum NG_{j-IH} = NG_{1-IH} + NG_{2-IH} + NG_{3-IH} + NG_{4-IH} + NG_{5-IH} \qquad (5)$$

In Equation 6, augmentation coefficients shown in Table 4.1 are applied to all floors and natural gas consumptions of all floors converted to the ground floor natural gas consumption.

$$\begin{aligned} NG_{T-IH} &= \sum NG_{j-IH} \\ &= NG_{1-IH} + NG_{1-IH} + NG_{1-IH} + 1{,}05\ NG_{1-IH} \\ &\quad + 1{,}10\ NG_{1-IH} = 5{,}15\ NG_{1-IH} \end{aligned} \qquad (6)$$

Natural gas consumption of DH system building's ground floor is calculated with Equation 7.

$$NG_{1-IH} = \frac{NG_{T-IH}}{5{,}15} \tag{7}$$

Similar calculation was made for sample DH, results is presented in Figure 4.3.

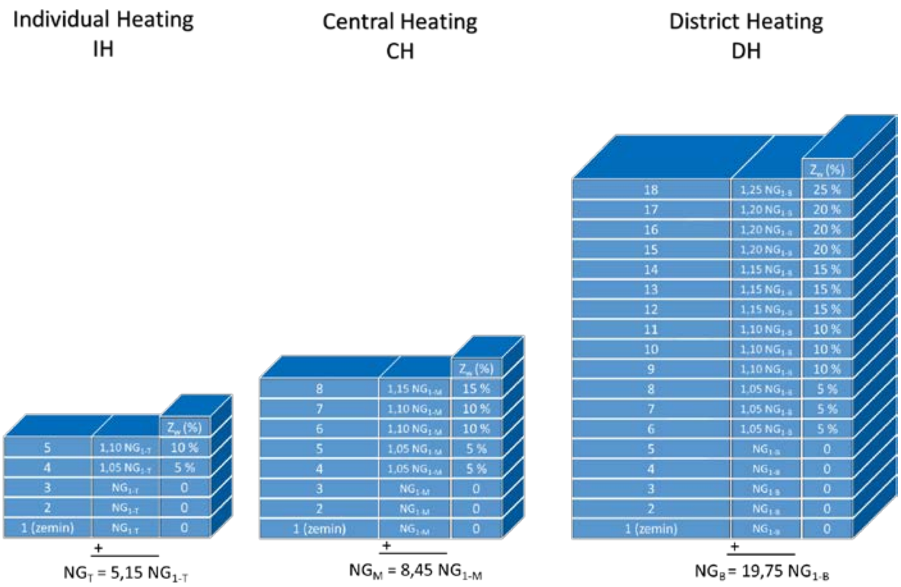

Figure 4.3. Natural gas consumptions of each floor

Natural gas consumption of ground floor for each building are calculated as below. Scheme of the results of Step 1 is shown on the Figure 4.4.

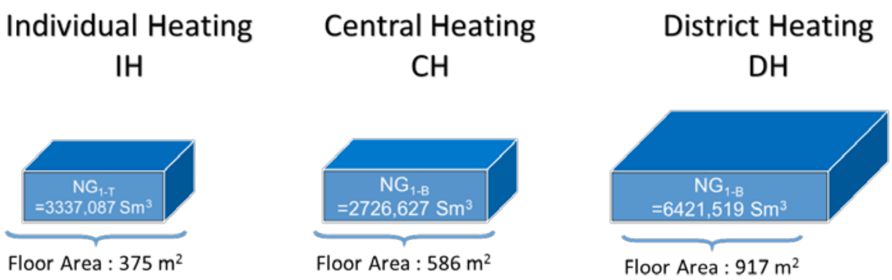

Figure 4.4. Results of Step 1

$$NG_{1-IH} = \frac{NG_{T-IH}}{5,15} = \frac{17\ 186}{5,15} = 3337,087\ Sm^3$$

$$NG_{1-CH} = \frac{NG_{T-CH}}{8,45} = \frac{23\ 040}{8,45} = 2726,627\ Sm^3$$

$$NG_{1-DH} = \frac{NG_{T-DH}}{19,75} = \frac{126\ 825}{19,75} = 6421,519\ Sm^3$$

Step 2) Natural gas consumption of ground floors for unit area

In this step, results of Step 1 are divided by floor area of each sample and natural gas consumption of ground floors for unit area were obtained. Figure 4.5 shows the schematic explanation of this step.

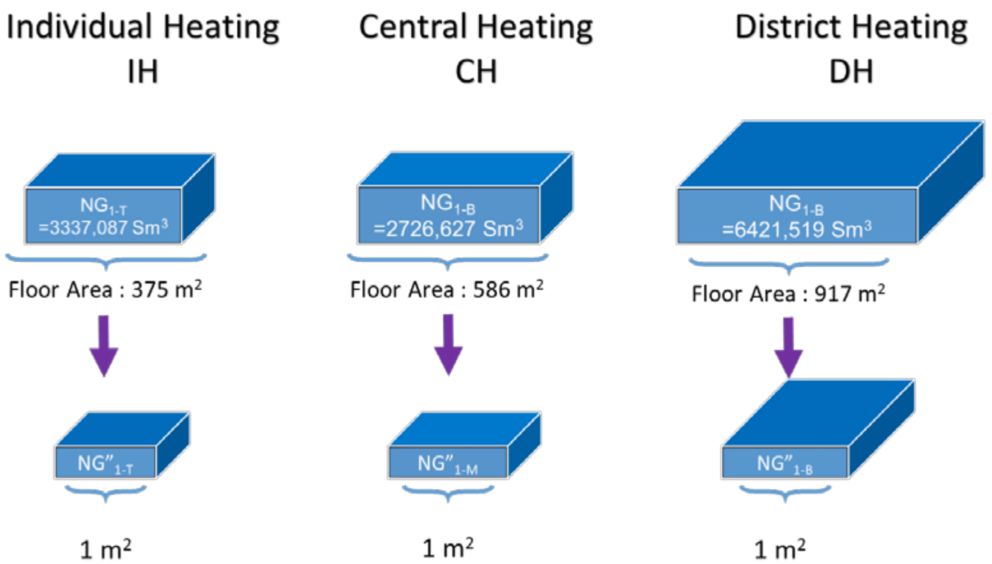

Figure 4.5. Natural gas consumptions of ground floors for unit area

Natural gas consumption of ground floor of the each building is calculated as below. Here unit area is denoted by the super-script double prime (”).

$$NG"_{1-IH} = \frac{NG_{1-IH}}{375\ m^2} = \frac{3337{,}087\ Sm^3}{375\ m^2} = 8{,}8989\,\frac{Sm^3 - NG}{m^2}$$

$$NG"_{1-CH} = \frac{NG_{1-CH}}{586\ m^2} = \frac{2726{,}627\ Sm^3}{586\ m^2} = 4{,}6529\ \frac{Sm^3 - NG}{m^2}$$

$$NG"_{1-DH} = \frac{NG_{1-DH}}{917\ m^2} = \frac{6421{,}519\ Sm^3}{917\ \ m^2} = 7{,}0027\ \frac{Sm^3 - NG}{m^2}$$

Step 3) Natural gas consumption for unit area is calculated according to the number of floor of reference building, 8 floors

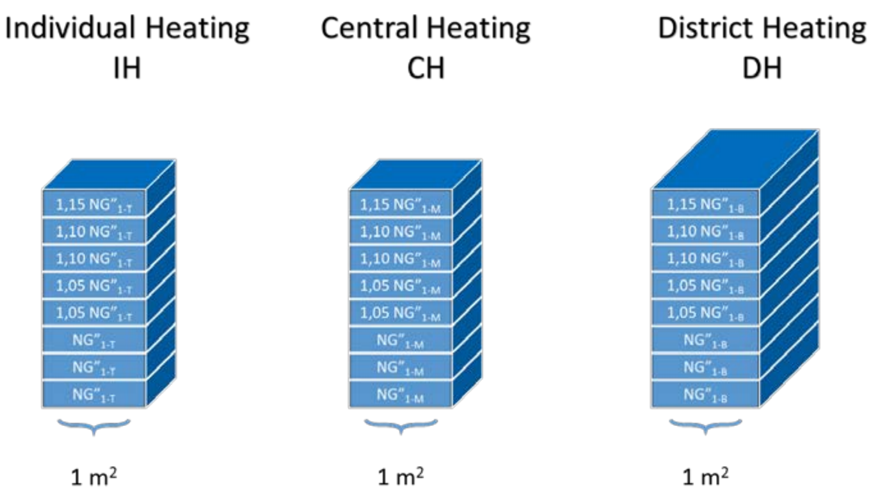

Figure 4.6. Scheme for Step 3.

Augmentations of high floors are taken into account to calculate the natural gas consumption of the unit area for 8 floors shown in Table 4.1. Therefore, natural gas consumptions of ground floor on unit area are multiplied with augmented floor numbers for 8 floors.

$$NG"_{IH} = 8{,}45 \times NG"_{1-IH} = 8{,}45 \times 8{,}8989$$
$$= 75{,}196 \frac{Sm^3 - NG}{m^2} \cdot 8\, floor$$

$$NG"_{CH} = 8{,}45 \times NG"_{1-CH} = 8{,}45 \times 4{,}653$$
$$= 39{,}317 \frac{Sm^3 - NG}{m^2} \cdot 8\, floor$$

$$NG"_{DH} = 8{,}45 \times NG"_{1-DH} = 8{,}45 \times 7{,}003$$
$$= 59{,}173 \frac{Sm^3 - NG}{m^2} \cdot 8\, floor$$

Step 4) Natural gas consumption for 8 floors in unit area is multiplied with reference floor area, 586 m^2.

In this step, floor areas of sample buildings are equalized to the reference floor area. The schematic explanation of this step can be seen on Figure 4.7.

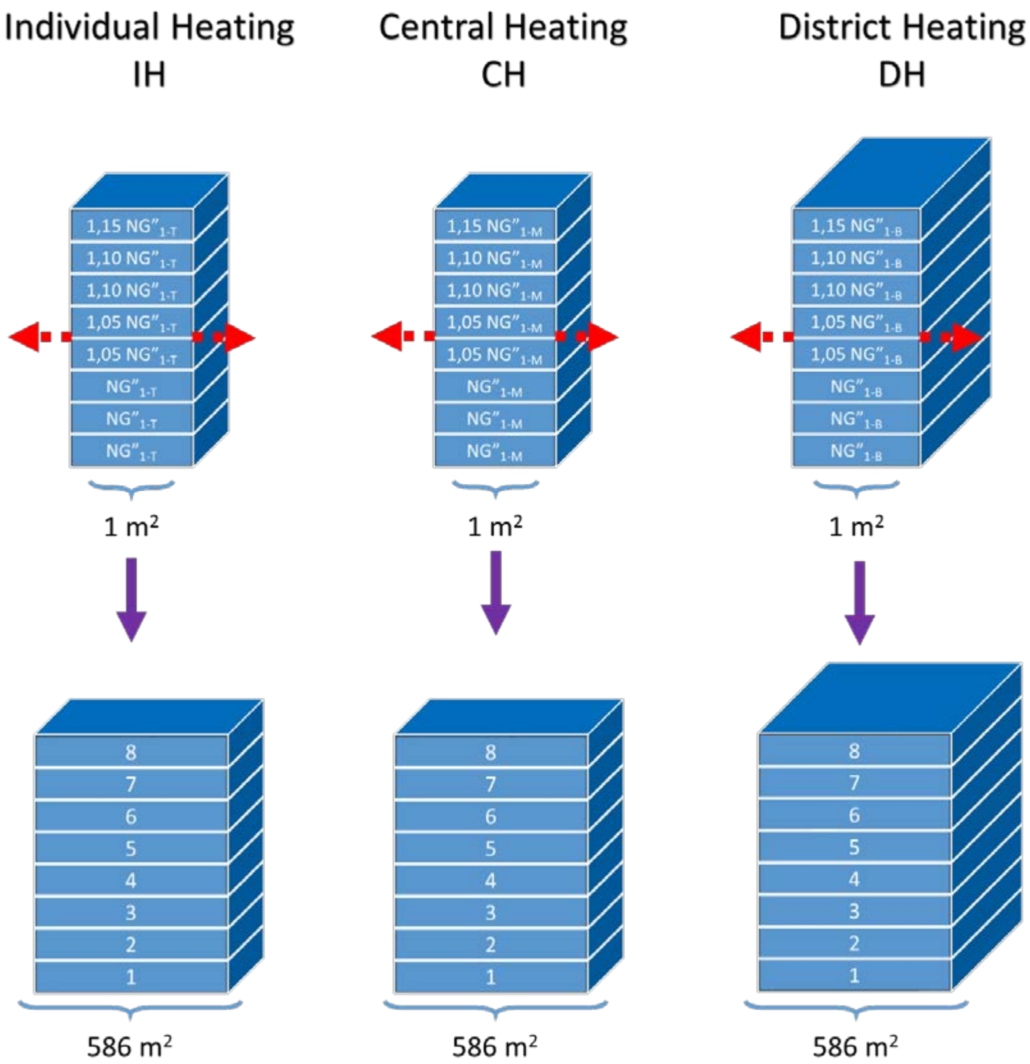

Figure 4.7. Schematic explanation for Step 4

Results of the calculations of Step 4 can be obtained as below:

$$NG_{IH} = NG"_{IH} \times 586\ m^2 \ = 44\ 064{,}682\ \ (Sm^3 - NG)$$

$$NG_{CH} = NG"_{CH} \times 586\ m^2 = \ 23\ 040{,}000\ (Sm^3 - NG)$$

$$NG_{DH} = \ NG"_{DH} \times 586\ m^2 \ = \ 34\ 675{,}502\ (Sm^3 - NG)$$

Step 5) Buildings exterior wall areas are adjusted to reference exterior wall area

Since the exterior wall areas of sample building with IH system and reference building are equal, only the sample building with DH system is adjusted proportionally to reference exterior wall area in this step. Figure 4.8 shows the schematic explanation of this step.

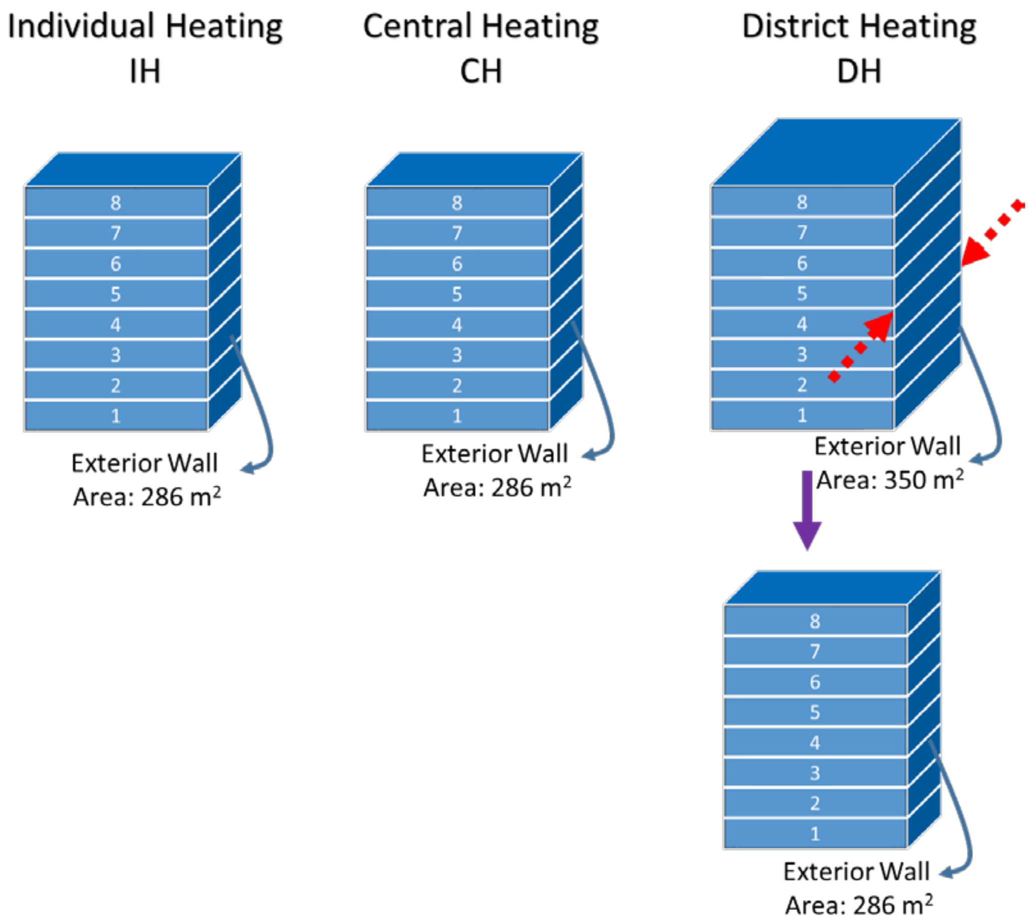

Figure 4.8. Schematic explanation of the area adjustment for exterior wall

Proportional adjustment based on Equation 1 is applied as below:

$$\frac{NG_{T-ref}}{(NG_T)_{IH,CH,DH}} = \frac{U_{ref}A_{ref}\left(T_{i_{ref}} - T_{o_{Bursa}}\right)}{U_{IH,CH,DH}A_{IH,CH,DH}\left(T_{i_{IH,CH,DH}} - T_{o_{Bursa}}\right)} \tag{8}$$

In this step, only exterior wall area is adjusted, inner air temperature, T_i, and overall wall heat transfer coefficient, U, of the adjusted building and the reference building adjustments is applied in the Step 6 and Step 7 respectively. Thus, in this step, these parameters for each building are assumed as equal to reference building and Equation 8 is simplified as Equation 9.

$$U_{ref} = U_{IH,CH,DH}$$

$$\left(T_{i_{ref}} - T_{o_{Bursa}}\right) = \left(T_{i_{IH,CH,DH}} - T_{d_{Bursa}}\right)$$

$$\frac{NG_{T-ref}}{(NG_T)_{IH,CH,DH}} = \frac{A_{ref}}{A_{IH,CH,DH}} \tag{9}$$

$$NG_{T-ref} = (NG_T)_{IH,CH,DH} \cdot \frac{A_{ref}}{A_{IH,CH,DH}} \tag{10}$$

With Equation 10, outer wall adjustment is applied to DH sample as below:

$$NG_{T-ref} = (NG_T)_{DH} \cdot \frac{A_{ref}}{A_{DH}}$$

$$= 34\,675{,}502\ (Sm^3 - NG) \cdot \frac{286}{350} = 28\,334{,}839\ (Sm^3 - NG)$$

Step 6) Inner air temperature of buildings are adjusted proportionally

By the similar approach with previous step, just one parameter is adjusted; other parameters are assumed equal to the reference building. Therefore in this step, Equation 8 is simplified as Equation 11.

$$U_{ref} = U_{IH,CH,DH}$$
$$A_{ref} = A_{IH,CH,DH}$$

$$\frac{NG_{T-ref}}{(NG_T)_{IH,CH,DH}} = \frac{\left(T_{i_{ref}} - T_{o_{Bursa}}\right)}{(T_{i_{IH,CH,DH}} - T_{o_{Bursa}})} \tag{11}$$

$$NG_{T-ref} = (NG_T)_{IH,CH,DH} \frac{\left(T_{i_{ref}} - T_{o_{Bursa}}\right)}{(T_{i_{IH,CH,DH}} - T_{o_{Bursa}})} \tag{12}$$

Inner air temperature of reference building is 23°C and, according to the TS 2164, outer winter temperature of Bursa -6°C.

$$T_{i_{ref}} = 23\ °C$$
$$T_{d_{Bursa}} = -6\ °C$$

$$NG_{T-ref} = (NG_T)_{IH,CH,DH} \cdot \frac{(23+6)}{\left(T_{i_{IH,CH,DH}} + 6\right)} \qquad (13)$$

According to the data collected during the field research, inner temperature of sample IH is less than sample CH and DH. Therefore in this study, inner temperatures of IH, CH and DH samples are assumed 22°C, 23°C and 24°C respectively.

With Equation 13, inner air temperature adjustment for sample IH is applied as below:

$$NG_{T-ref} = (NG_T)_{IH} \cdot \frac{(23+6)}{(22+6)}$$

$$= 44\ 064{,}682 \cdot \frac{29}{28} = 45\ 638{,}420\ (Sm^3 - NG)$$

Inner air temperature adjustment for sample DH is applied as below:

$$NG_{T-ref} = (NG_T)_{DH} \cdot \frac{(23+6)}{(24+6)}$$

$$= 28\ 334{,}839 \cdot \frac{29}{30} = 27\ 390{,}344\ (Sm^3 - NG)$$

Step 7) Overall wall heat transfer coefficients, U-values, is adjusted proportionally

As it is considered in previously two steps, only one parameter is adjusted for this step too. Rest of the parameters is assumed equal to the reference building. Therefore, Equation 8 is simplified as Equation 14 in this case.

$$\frac{NG_{T-ref}}{(NG_T)_{IH,CH,DH}} = \frac{U_{ref}}{U_{IH,CH,DH}} \tag{14}$$

$$NG_{T-ref} = (NG_T)_{IH,CH,DH} \frac{U_{ref}}{U_{IH,CH,DH}} \tag{15}$$

According to the TS 825 U-values of the sample buildings with IH, CH and DH systems are 1,040 W/m^{2}K, 0,614 W/m^{2}K and 0,822 W/m^{2}K respectively as it can be seen on Appendix B in detail.

Overall wall heat transfer coefficient adjustments for IH and DH samples are applied in Equation 15 as below:

$$NG_{T-ref} = (NG_T)_{IH} \frac{U_{ref}}{U_{IH}}$$

$$= 45\ 638{,}420 \cdot \frac{0{,}614}{1{,}040} = 26\ 944{,}221\ (Sm^3 - NG)$$

$$NG_{T-ref} = (NG_T)_{DH} \frac{U_{ref}}{U_{DH}}$$

$$27\ 390{,}344 \cdot \frac{0{,}614}{0{,}822} = 20\ 459{,}454\ \ (Sm^3 - NG)$$

4.2. Adjusted Natural Gas Consumptions and Comparison of Results

After the application of augmentations and adjustments listed in 7 steps, natural gas consumptions of sample buildings on equal basis is presented in Table 4.2.

Table 4.2. Adjusted Natural Gas Consumptions for Sample Buildings

	IH	CH	DH
NG Consumption/Year (Sm^3)	26944,22	23040	20459,454

In order to obtain per unit natural gas consumption for each building, total annual natural gas consumption amounts are divided by the reference floor area, which is 4688 m^2. Adjusted natural gas consumptions for unit floor area of sample buildings can be seen on Table 4.3.

Table 4.3. Adjusted Natural Gas Consumptions for Unit Area for Sample Buildings

	IH	CH	DH
NG Consumption for Unit Area (Sm3/ m2)	5,747	4,915	4,364

According to 2014 values noticed in Emission Factors for Greenhouse Gas Inventories of IPCC, emission factor for natural gas is recorded as 56,1 kg CO_2 equivalent for 1 Giga-Joule generated energy ($kgCO_2/GJ$). In addition to IPCC value, according to the unit conversion regulation of Annunciation for Accurate Billing Principles on Determination of Amount of the Natural Gas Consumption of EMRA (Article 4), total emitted CO_2 amount can be calculated as 2,1493 $kgCO_2$ during the combustion of 1 Sm^3 of natural gas with 100% combustion efficiency.

By taking into consideration the combustion efficiencies of boilers, for each sample building annual CO_2 emissions and annual CO_2 emissions for unit area are calculated. Although there are 15 different kombi boilers with 15 different combustion efficiencies for each apartment of the sample building with IH system, for this study building is considered as one volume. Therefore, the efficiencies of 15 kombi boilers of IH system building is taken into account by using weighted arithmetic mean of natural gas consumptions of 15 apartments for the year. It is calculated 0,913 by the weighted arithmetic mean denoted, WAM, in calculations.

$$CO_{2_{IH,CH,DH}}" = DG"_{IH,CH,DH} \cdot \eta_{boiler} \cdot 2{,}1493$$

$$CO_{2_{IH}}" = DG"_{IH} \cdot \eta_{boiler-WAM} \cdot 2{,}1493 \ = 5{,}747 \cdot 0{,}913 \cdot 2{,}1493$$
$$= 11{,}282\ (kgCO_2)/m^2$$

$$CO_{2_{CH}}" = DG"_{CH} \cdot \eta_{boiler} \cdot 2{,}1493 \ = 4{,}915 \cdot 0{,}930 \cdot 2{,}1493$$
$$= 9{,}827\ \ (kgCO_2)/m^2$$

$$CO_{2_{DH}}" = DG"_{DH} \cdot \eta_{boiler} \cdot 2{,}1493 \ = 4{,}364 \cdot 0{,}925 \cdot 2{,}1493$$
$$= 8{,}679\ \ (kgCO_2)/m^2$$

To be able to find out the energy consumption levels of the sample buildings based on Article 4 of related EMRA regulation 1 Sm^3 natural gas is considered as equivalent of 10,64 kWh energy. The energy consumptions for unit area of sample buildings are calculated as below:

$$q_{IH}" = DG"_{IH} \cdot 10{,}64 = 5{,}747\ (Sm^3 - DG)/m^2 \cdot 10{,}64 = 61{,}153\ kWh/m^2$$

$$q_{CH}" = DG"_{CH} \cdot 10{,}64 = 4{,}915\ (Sm^3 - DG)/m^2 \cdot 10{,}64 = 52{,}292\ kWh/m^2$$

$$q_{DH}" = DG"_{DH} \cdot 10{,}64 = 4{,}364\ (Sm^3 - DG)/m^2 \cdot 10{,}64 = 46{,}435\ kWh/m^2$$

4.3. Citywide Natural Gas Consumptions and CO_2 Emissions

For the last part of the methodology citywide calculations for total natural gas consumption and CO_2 emissions are calculated based on the total residential area that is heated by IH, CH and DH systems.

For this part BBS data set of BURSAGAZ is used since the area based on interior installation is not very well recorded on the data set. Using BBS data brings a resolution problem for the methodology. According to the EMRA regulation mentioned previously BBS is an area category to define the subscription price for each consumer. According to this regulation, 1 BBS is considered as the net area that is equal to or less than 200 m^2 for the residence. After 200 m^2 every each additional 100 m^2 means 1 more BBS (Table 4.4).

Table 4.4. BBS Definitions According to EMRA Regulation

Number of BBS	Defined Net Residential Area Interval
1 BBS	000 m^2 < Net Area of Residence ≤ 200 m^2
2 BBS	200 m^2 < Net Area of Residence ≤ 300 m^2
3 BBS	300 m^2 < Net Area of Residence ≤ 400 m^2
4 BBS	400 m^2 < Net Area of Residence ≤ 500 m^2

In this BBS resolution to be able to calculate a reliable total residential area for Bursa, the residential net areas are researched. Since it cannot be found in any reliable data source including the scholar literature and the database of TUIK and the Ministry of Environment and Urbanization, the analyses of the distribution company regarding the average net residential areas based on BBS calculation is used. According to these analyses, total number of subscribers using IH, CH and DH system are considered as the first BBS. Rest of the total number of BBS considered as the second BBS. Numbers of residences having 3 BBS are neglected according to the analysis of the company (Table 4.5).

Table 4.5. Numbers of BBS for Each Heating System

	IH	**CH**	**DH**
Number of Consumers	531.070,00	27.029,00	9.607,00
Number of Total BBS	658.527,00	48.111,00	17.772,00
Number of 2nd BBS	127.457,00	21.082,00	8.165,00

Starting from 75 m^2, area weighted ranges are assigned for each additional 25 m^2 according to the analyses of company employee working for BBS records. For the second BBS a similar assignment is executed with net area ranges for additional 10 m^2, 25 m^2, 50 m^2, 75 m^2 and 100 m^2 to the 200 m^2 of second BBS. Since, all of the consumers recorded as 2 BBS including 200 m^2 sum of these three value have been taken as the total residential areas for IH, CH and DH system users in Bursa (Table 4.6).

After total residential area is calculated, natural gas consumptions and CO_2 emissions per unit areas of sample buildings are included to the citywide projections. Therefore the total residential natural gas consumption and total residential carbon emissions of Bursa can be calculated according to the methodology. Results of the calculations can be seen on the Table 4. 7.

Table 4.6. Residential Area Calculations for Bursa

1st BBS		IH SYSTEM		CH SYSTEM		DH SYSTEM	
Area (m2)	**Range**	**1st BBS**	**Area (m2)**	**1st BBS**	**Area (m2)**	**1st BBS**	**Area (m2)**
75,00	0,10	53.107,00	3.983.025,00	2.702,90	202.717,50	960,70	72.052,50
100,00	0,30	159.321,00	15.932.100,00	8.108,70	810.870,00	2.882,10	288.210,00
125,00	0,39	207.117,30	25.889.662,50	10.541,31	1.317.663,75	3.746,73	468.341,25
150,00	0,25	132.767,50	19.915.125,00	6.757,25	1.013.587,50	2.401,75	360.262,50
175,00	0,05	26.553,50	4.646.862,50	1.351,45	236.503,75	480,35	84.061,25
200,00	0,01	5.310,70	1.062.140,00	270,29	54.058,00	96,07	19.214,00
Total	1,00	531.070,00	**67.445.890,00**	27.029,00	**3.432.683,00**	9.607,00	**1.220.089,00**
2nd BBS		**IH SYSTEM**		**CH SYSTEM**		**DH SYSTEM**	
200 + Area (m2)	**Range**	**2nd BBS**	**Area (m2)**	**2nd BBS**	**Area (m2)**	**2nd BBS**	**Area (m2)**
10,00	0,40	50.982,80	509.828,00	8.432,80	84.328,00	3.266,00	32.660,00
25,00	0,40	50.982,80	1.274.570,00	8.432,80	210.820,00	3.266,00	81.650,00
50,00	0,14	17.843,98	892.199,00	2.951,48	147.574,00	1.143,10	57.155,00
75,00	0,05	6.372,85	477.963,75	1.054,10	79.057,50	408,25	30.618,75
100,00	0,01	1.274,57	127.457,00	210,82	21.082,00	81,65	8.165,00
Total	1,00	127.457,00	**3.282.017,75**	21.082,00	**542.861,50**	8.165,00	**210.248,75**
200*BBS2			**25.491.400,00**		**4.216.400,00**		**1.633.000,00**
TOTAL AREA (m2)		**96.219.307,75**		**8.191.944,50**		**3.063.337,75**	

Table 4.7. Calculated Natural Gas Consumption and Carbon Emission for Bursa

	IH	**CH**	**DH**	**TOTAL**
Residential Area (m^2)	96.219.307,75	8.191.944,50	3.063.337,75	107.474.590,00
NG Consumption per Unit Area (Sm^3/m^2)	5,75	4,92	4,36	-
Residential NG Consumption (Sm^3)	552.972.361,64	40.263.407,22	13.368.405,94	606.604.174,80
CO_2 Emission per Unit Area ($kgCO_2/m^2$)	12,35	10,57	9,38	-
Residential CO_2 Emission ($kgCO_2$)	1.188.779.983	86.558.272,84	28.739.399,09	1.304.077.655

4.4. Projections

The purpose of this research is to develop a methodology to evaluate energy efficiency performance of three different residential heating systems by using the actual data of residential natural gas consumption. Such a methodology is assumed to be an effective support tool for policymaking to mitigate energy use and carbon emissions in cities. Based on the results on efficiency performances that are shown in Chapter 3, some citywide outcomes can be projected for Bursa city. The citywide outcomes will indicate energy saving and GHG mitigation potential of likely policies that regulate the transition from individual heating systems to central and district ones.

Natural gas consumption levels and related CO_2 emissions per unit area are calculated by means of the comparison methodology for each different heating system. The total citywide residential areas heated by IH, CH and DH systems are found by using the subscription data of the natural gas distribution company in Bursa. Therefore citywide residential natural gas consumption level and related CO_2 emissions of Bursa are calculated as the baseline scenario. The baseline scenario can be seen on Table 4.8.

Table 4.8. Residential Natural Gas Consumption and Carbon Emissions of Bursa City

Heating Systems	Total Urban Residential Area (m^2)	Natural Gas Consumption per unit area (Sm^3/m^2)	Total Natural Gas Consumption (Sm^3)	CO_2 Emissions per unit area ($kgCO_2/m^2$)	Total CO_2 Emissions ($kgCO_2$)
IH	96.219.308	5,75	552.972.367	12,35	1.188.779.983
CH	8.191.945	4,92	40.263.407	10,57	86.558.273
DH	3.063.338	4,36	13.368.406	9,38	28.739.399
TOTAL	107.474.590		606.604.175		1.304.077.655

Six projection scenarios have been generated with regard to replace existing residential IH systems with CH or DH systems, and CH systems with DH systems with the aim of mitigating natural gas consumption and carbon emissions in Bursa City. Marginal cases are also considered for projections to be able to see the marginal mitigation effects of alternative heating systems. Results of the projection scenarios have been compared with in both total amounts and the percentages for mitigations with respect to the alternatives. The consolidated results are shown on the graphs given as Figure 4.9 and Figure 4.10 respectively. Since emission calculations are based on the amount of natural gas consumed (see Chapter 3), the percentages of mitigation for energy consumption and carbon emissions are equal. At the end of the projections related graphs can be seen on Figure 4.11 and Figure 4.12.

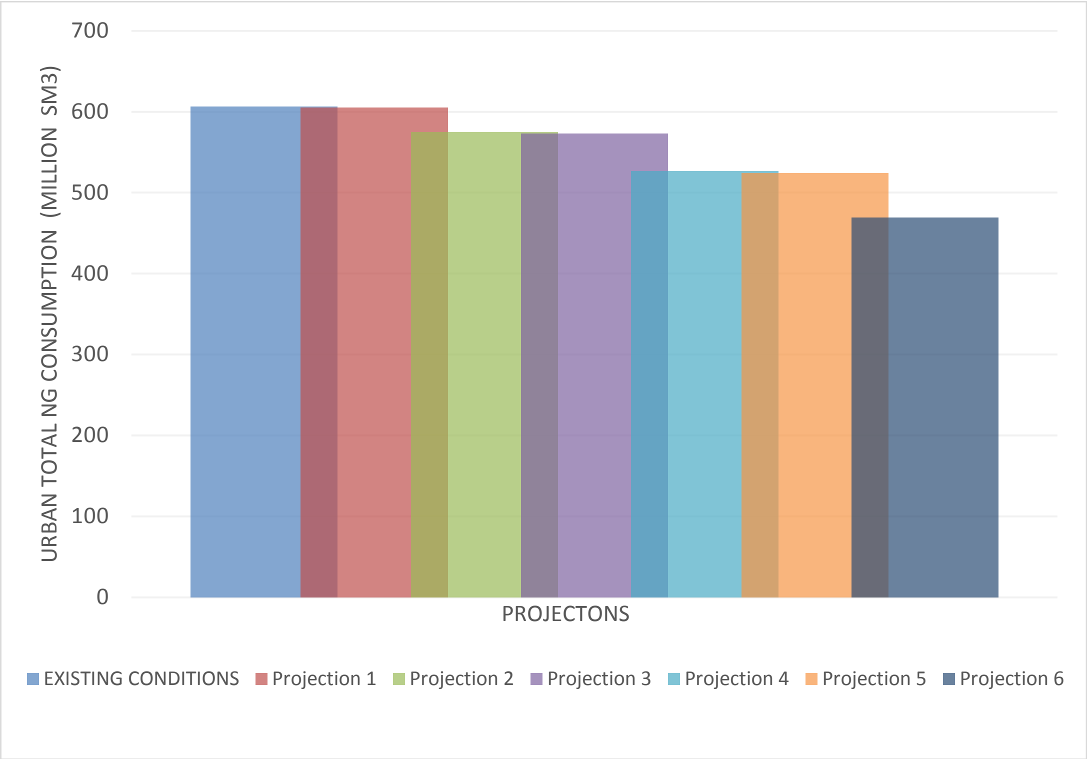

Figure 4.9. Total residential natural gas consumption for different scenarios

The first projection assumes that 40% of the existing CH systems would be converted into DH systems. In this case, it is seen that natural gas consumption and carbon emission of IH systems are not changed however natural gas consumption of CH systems decreases by 16.105.362 Sm^3. Whereas the amount of natural gas consumed by DH systems increases by 14.299.858 Sm^3 with respect to the existing natural gas consumption levels. As per the first scenario, total carbon emissions are found to decrease by almost 4 million kg per year (Table 4.9). In other words, the emissions mitigation potential of the first scenario appears as 0,3%, which is very minimal and not very plausible for policymaking purposes.

Table 4.9. Natural Gas Consumption and Related Carbon Emission for Projection Scenario 1

Heating Systems	Total Urban Residential Area (m^2)	Natural Gas Consumption per unit area (Sm^3/m^2)	Total Natural Gas Consumption (Sm^3)	CO_2 Emissions per unit area ($kgCO_2/m^2$)	Total CO_2 Emissions ($kgCO_2$)
IH	96.219.308	5,75	552.972.367	12,35	1.188.779.983
CH	4.915.167	4,92	24.158.044	10,57	51.934.964
DH	6.340.116	4,36	27.668.264	9,38	59.481.235
TOTAL	107.474.590		604.798.670		1.300.196.181
MITIG.	0,000%		0,298%		0,298%

Projection 1: 40 % of the existing CH converted into DH

The second projection scenario assumes that 40% of the existing IH systems would be replaced with CH systems. In this case, natural gas consumption and carbon emission of DH systems remain same however natural gas consumption of IH systems decreases by 221.188.944 Sm^3. This difference corresponds to an increase of 189.167.159 Sm^3 consumption for CH systems, indicating a citywide energy saving of 32.021.785 Sm^3 per year. Related CO_2 emissions for IH systems are found to decrease by 475.511.993 kg per year with respect to existing conditions. As the additional CO_2 emissions of CH systems equals to 406.671.558 kg, CO_2 mitigation potential of the second scenario appears as almost 70 million $kgCO_2$ per year. The rate of mitigation for scenario 2 is calculated as 5,3% (Table 4.10).

Table 4.10. Natural Gas Consumption and Related Carbon Emission for Projection Scenario 2

Heating Systems	Total Urban Residential Area (m^2)	Natural Gas Consumption per unit area (Sm^3/m^2)	Total Natural Gas Consumption (Sm^3)	CO_2 Emissions per unit area ($kgCO_2/m^2$)	Total CO_2 Emissions ($kgCO_2$)
IH	57.731.585	5,75	331.783.417	12,35	713.267.990
CH	46.679.668	4,92	229.430.566	10,57	493.229.831
DH	3.063.338	4,36	13.368.406	9,38	28.739.399
TOTAL	107.474.590		574.582.389		1.235.237.220
MITIG.	0,000%		5,279%		5,279%

Projection 2: 40 % of the existing IH converted into CH

The third projection scenario is based on the assumption that 40% of the existing IH systems would be converted into CH systems and 40% of the existing CH systems would be turned into DH systems. The results of this scenario can be seen on Table 4.11. In this case, it has been found that total natural gas consumption in Bursa could be reduced by 33.827.290 Sm^3, owing mostly to the shift from individual systems to central systems. Total annual CO_2 mitigation due to energy saving is thus found to be around 73 million kg. The rate of CO_2 mitigation is around 5,6% for the third projection scenario and it should be noted that this scenario is the optimum one when compared to the marginal scenarios.

Table 4.11. Natural Gas Consumption and Related Carbon Emission for Projection Scenario 3

Heating Systems	Total Urban Residential Area (m^2)	Natural Gas Consumption per unit area (Sm^3/m^2)	Total Natural Gas Consumption (Sm^3)	CO_2 Emissions per unit area ($kgCO_2/m^2$)	Total CO_2 Emissions ($kgCO_2$)
IH	57.731.585	5,75	331.783.417	12,35	713.267.990
CH	43.402.890	4,92	213.325.203	10,57	458.606.522
DH	6.340.116	4,36	27.668.264	9,38	59.481.235
TOTAL	107.474.590		572.776.885		1.231.355.747
MITIG.	0,000%		5,577%		5,577%

Projection 3: 40 % of the existing IH converted into CH and 40 % of the existing CH converted into DH

It should be emphasized that the rest of the projection scenarios include marginal or in other words more ambitious assumptions in order to understand the energy and carbon emissions mitigation potential of more fundamental policy options. These options might be difficult to implement in the short-run but could be considered as key targets in mid- and long-run policymaking approaches. As it can be seen on Table 4.12, the fourth projection scenario is based on the assumption that all of the IH systems in Bursa are converted into CH systems. In case this scenario is implemented, total natural gas consumption for residential heating in Bursa city could be reduced to 526.549.710 Sm^3 from 606.604.174 Sm^3, which corresponds to a decrease by 13.2%. Likewise, CO_2 emissions that originate from residential natural gas consumption could be reduced by 172 million $kgCO_2$ per annum. In other words, the fourth scenario has a potential to mitigate carbon emissions by 13,12% per year.

Table 4.12. Natural Gas Consumption and Related Carbon Emission for Projection Scenario 4

Heating Systems	Total Urban Residential Area (m^2)	Natural Gas Consumption per unit area (Sm^3/m^2)	Total Natural Gas Consumption (Sm^3)	CO_2 Emissions per unit area ($kgCO_2/m^2$)	Total CO_2 Emissions ($kgCO_2$)
IH	-	5,75	-	12,35	-
CH	104.411.252	4,92	513.181.305	10,57	1.103.237.169
DH	3.063.338	4,36	13.368.406	9,38	28.739.399
TOTAL	107.474.590		526.549.711		1.131.976.568
MITIG.	0,000%		13,197%		13,197%
Projection 4: 100 % of the existing IH converted into CH					

For the fifth projection shown in Table 4.13, it is assumed that 50% of CH systems are turned into DH system as an addition to the previous projection scenario. In this case, total natural gas consumption and carbon emissions are found to decrease by 13.6% annually. In other words, in case the fifth scenario is implemented, total natural gas consumption for residential heating in Bursa could be decreased by 82.311.344 Sm^3 and carbon emissions by almost 177 million $kgCO_2$.

Table 4.13. Natural Gas Consumption and Related Carbon Emission for Projection Scenario 5

Heating Systems	Total Urban Residential Area (m^2)	Natural Gas Consumption per unit area (Sm^3/m^2)	Total Natural Gas Consumption (Sm^3)	CO_2 Emissions per unit area ($kgCO_2/m^2$)	Total CO_2 Emissions ($kgCO_2$)
IH	-	5,75	-	12,35	-
CH	100.315.280	4,92	493.049.601	10,57	1.059.958.033
DH	7.159.310	4,36	31.243.229	9,38	67.166.693
TOTAL	107.474.590		524.292.830		1.127.124.726
MITIG.	0,000%		13,569%		13,569%

Projection 5: 100 % of the existing IH converted into CH and 50 % of the existing CH converted into DH

The sixth projection scenario is the most ambitious one. In this scenario, it is assumed that all residential buildings in Bursa would be heated by DH systems, which are the most efficient ones among the three heating systems. This marginal scenario means that all residential dwellings, which are being heated by IH and CH systems at present, will be connected to DH systems. Table 4.14 presents all of the energy consumption and related emissions that belongs to DH systems as foreseen in Projection Scenario 6. The likely energy and CO_2 emissions mitigations of the last scenario are calculated as 137.585.064 Sm3 and 295.780.370 $kgCO_2$. This means that if the last scenario is implemented, total residential natural gas consumption and its associated carbon emissions could be reduced by almost 23% compared to the baseline scenario. All in all, among all projection scenarios, the largest mitigation potential is hold by the last one. The cogeneration case for this projection can be seen on Appendix C, with its explanation and calculations.

Table 4.14. Natural Gas Consumption and Related Carbon Emission for Projection Scenario 6

Heating Systems	Total Urban Residential Area (m^2)	Natural Gas Consumption per unit area (Sm^3/m^2)	Total Natural Gas Consumption (Sm^3)	CO_2 Emissions per unit area ($kgCO_2/m^2$)	Total CO_2 Emissions ($kgCO_2$)
IH	-	5,75	-	12,35	-
CH	-	4,92	-	10,57	-
DH	107.474.590	4,36	469.019.111	9,38	1.008.297.284
TOTAL	107.474.590		469.019.111		1.008.297.284
MITIG.	0,000%		22,681%		22,681%
Projection 6: 100 % of the existing IH and CH converted into DH					

Table 4.15. The List and Calculations for the Projections

				Total Area for Bursa (m2)	NG Consumption per Unit Area (Sm3/m2)	NG Consumption for Bursa (Sm3)	CO2 Emission per Unit Area (kgCO2/m2)	CO2 Emission or Bursa (kgCO2)	NG Consumption Relative to Existing Condition (Sm3)	CO2 Emission Relative to Existing Condition (kgCO2)
EXISTING CONDITIONS			IH	96.219.307,75	5,75	552.972.361,64	12,35	1.188.779.983,05	-	-
			CH	8.191.944,50	4,92	40.263.407,22	10,57	86.558.272,84	-	-
			DH	3.063.337,75	4,36	13.368.405,94	9,38	28.739.399,09	-	-
			TOTAL	107.474.590,00		606.604.174,80		1.304.077.654,98	-	-
Projection 1	IH to CH	0	IH	96.219.307,75	5,75	552.972.361,64	12,35	1.188.779.983,05	-	-
	CH to DH	0,4	CH	4.915.166,70	4,92	24.158.044,33	10,57	51.934.963,70	16.105.362,89	34.623.309,13
	IH to DH	0	DH	6.340.115,55	4,36	27.668.264,26	9,38	59.481.234,51	- 14.299.858,32	- 30.741.835,41
			TOTAL	107.474.590,00		604.798.670,23		1.300.196.181,26	1.805.504,57	3.881.473,72
			MITTIGATION	0,000%		0,298%		0,298%		
Projection 2	IH to CH	0,4	IH	57.731.584,65	5,75	331.783.416,98	12,35	713.267.989,83	221.188.944,66	475.511.993,22
	CH to DH	0	CH	46.679.667,60	4,92	229.430.566,25	10,57	493.229.831,33	- 189.167.159,04	- 406.671.558,50
	IH to DH	0	DH	3.063.337,75	4,36	13.368.405,94	9,38	28.739.399,09	-	-
			TOTAL	107.474.590,00		574.582.389,18		1.235.237.220,26	32.021.785,62	68.840.434,72
			MITTIGATION	0,000%		5,279%		5,279%		
Projection 3	IH to CH	0,4	IH	57.731.584,65	5,75	331.783.416,98	12,35	713.267.989,83	221.188.944,66	475.511.993,22
	CH to DH	0,4	CH	43.402.889,80	4,92	213.325.203,37	10,57	458.606.522,20	- 173.061.796,15	- 372.048.249,36
	IH to DH	0	DH	6.340.115,55	4,36	27.668.264,26	9,38	59.481.234,51	- 14.299.858,32	- 30.741.835,41
			TOTAL	107.474.590,00		572.776.884,61		1.231.355.746,54	33.827.290,19	72.721.908,44
			MITTIGATION	0,000%		5,577%		5,577%		
Projection 4	IH to CH	1	IH	-	5,75	-	12,35	-	552.972.361,64	1.188.779.983,05
	CH to DH	0	CH	104.411.252,25	4,92	513.181.304,81	10,57	1.103.237.169,08	- 472.917.897,59	- 1.016.678.896,24
	IH to DH	0	DH	3.063.337,75	4,36	13.368.405,94	9,38	28.739.399,09	-	-
			TOTAL	107.474.590,00		526.549.710,75		1.131.976.568,17	80.054.464,05	172.101.086,81
			MITTIGATION	0,000%		13,197%		13,197%		
Projection 5	IH to CH	1	IH	-	5,75	-	12,35	-	552.972.361,64	1.188.779.983,05
	CH to DH	0,5	CH	100.315.280,00	4,92	493.049.601,20	10,57	1.059.958.032,66	- 452.786.193,98	- 973.399.759,82
	IH to DH	0	DH	7.159.310,00	4,36	31.243.228,84	9,38	67.166.693,36	- 17.874.822,90	- 38.427.294,27
			TOTAL	107.474.590,00		524.292.830,04		1.127.124.726,02	82.311.344,76	176.952.928,96
			MITTIGATION	0,000%		13,569%		13,569%		
Projection 6	IH to CH	0	IH	-	5,75	-	12,35	-	552.972.361,64	1.188.779.983,05
	CH to DH	1	CH	-	4,92	-	10,57	-	40.263.407,22	86.558.272,84
	IH to DH	1	DH	107.474.590,00	4,36	469.019.110,76	9,38	1.008.297.284,31	- 455.650.704,82	- 979.557.885,22
			TOTAL	107.474.590,00		469.019.110,76		1.008.297.284,31	137.585.064,04	295.780.370,67
			MITTIGATION	0,000%		22,681%		22,681%		

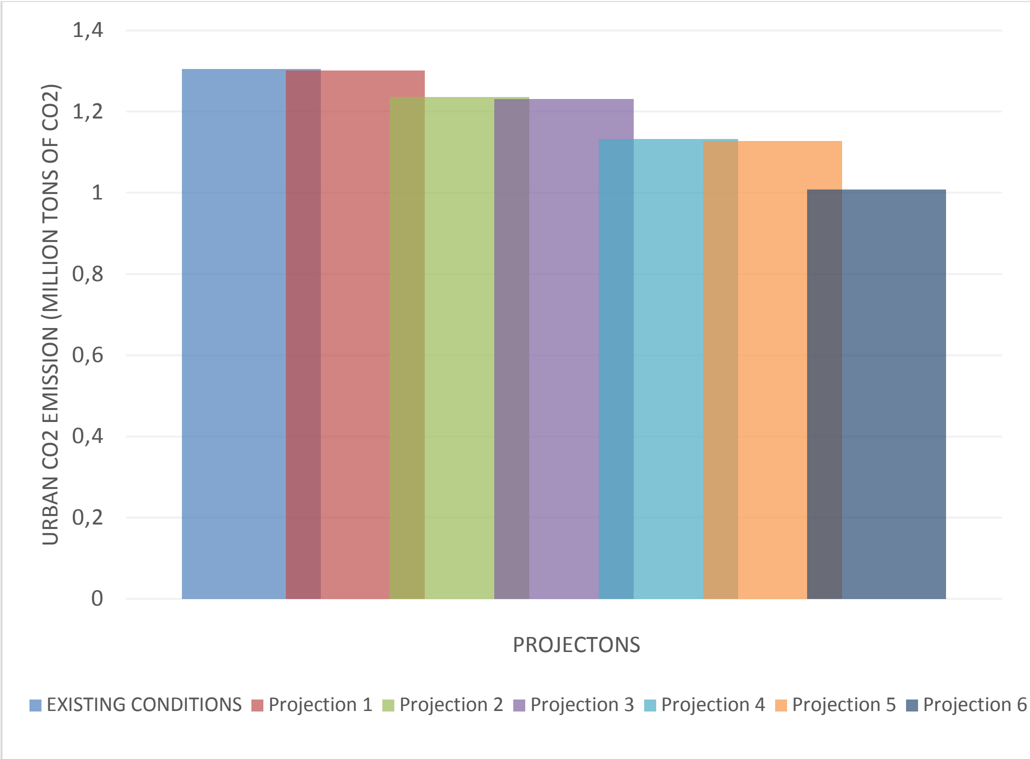

Figure 4.10. Total residential CO_2 emissions for different projections

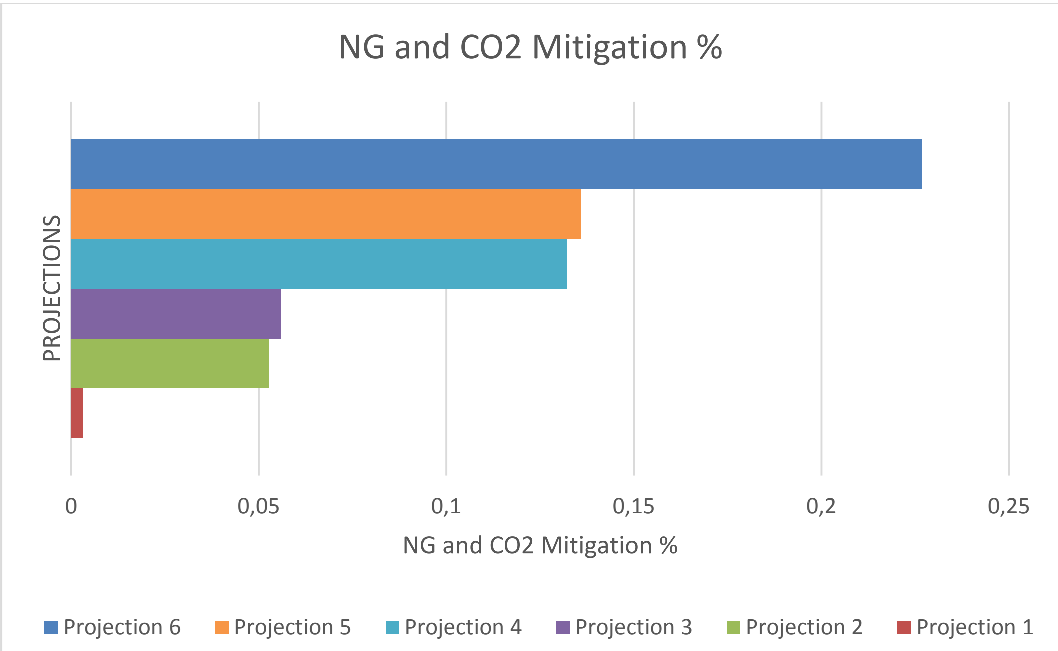

Figure 4.11. Mitigations rates for natural gas consumption and CO_2 emission

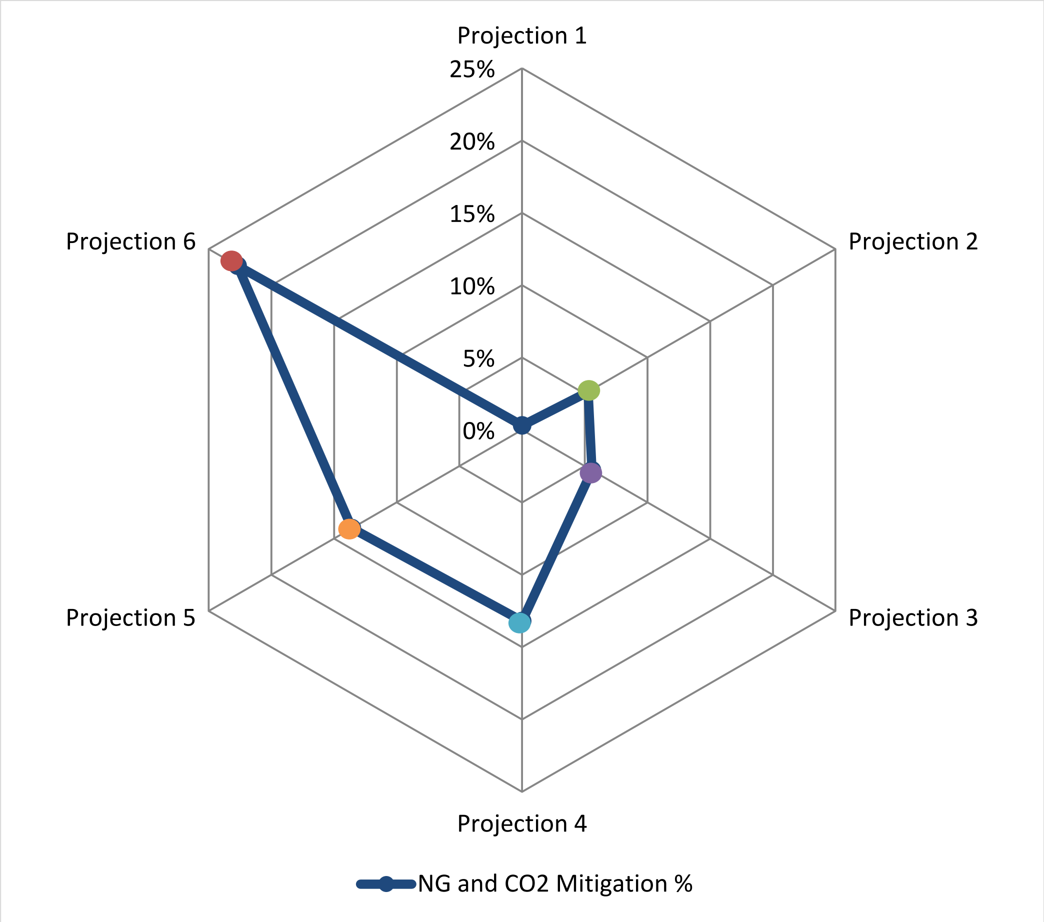

Figure 4.12. Mitigations rates for consumptions and emissions

CHAPTER 5

CONCLUSION AND DISCUSSIONS

5.1. Summary of the Research

In this research, energy efficiency in general and energy efficiency in residential units with a particular focus on natural gas consumption is considered. The main arguments that shaped the research are as follows: meeting the increasing demand for energy, providing security for energy supply, reducing dependency on energy imports and a policy towards reduction in energy use and greenhouse gas emissions in cities.

Main purpose of this research is to develop a methodology to calculate the differences between efficiency performance of three residential heating systems; namely individual, central and district heating systems. The methodology can be utilized by using actual data of residential natural gas consumption and is regarded as a support tool for policy-making.

As mentioned above, three different residential heating systems are selected to compare their natural gas consumption levels and associated carbon emissions. The key steps of the research are summarized and listed below:

1) Bursa city was selected as the case city and Nilufer Municipality as the case district.

2) The Natural Gas Distribution Company of Bursa (BURSAGAZ) was contacted to gather actual data on residential natural gas consumption. The data obtained from BURSAGAZ has been utilized in the research.

3) Based on the database provided by BURSAGAZ, a set of sample buildings with Individual Heating (IH), Central Heating (CH) and District Heating (DH) systems are determined.

4) After the elimination based on selection criteria, one sample building for each heating system was selected for the empirical research. The selection criteria included number of dwellings in each building, occupancy rates of the dwellings, total heating area of each building, common heating areas which are not residential, age of each building, situations of the building envelope insulations, buildings shapes, location of the buildings, sale and rent prices for dwelling units and the dwellers' profiles.

5) Natural gas consumption data by months are filtrated for every consumer of the company living in sample buildings.

6) Heated areas of the buildings are considered based on interior installation projects.

7) The thermal comfort conditions of the dwellers and exterior insulation condition of sample buildings and combustion efficiencies of boilers are defined during the field research.

8) Total natural gas consumption of sample buildings are calculated for 2014 according to the BURSAGAZ's billing database in terms of standard cubic meter (Sm3).

9) Combustion efficiencies are considered to be able to calculate the carbon emissions that originate from actual residential natural gas consumption in unit of kilograms of CO_2 equivalent ($kgCO_2$).

10) Augmentations for high floors are implemented to the samples according to the TS 2164 standard. These calculations are completed in four steps as explained

in methodology chapter. CH building is selected as the reference building and rest of the samples are equalized to the reference buildings floor number. Total heating load is considered as proportional with natural gas consumption levels.

11) Augmentations for orientations of the TS 2164 standard are calculated as zero in over all, since the samples are considered as a one heated volume.

12) Adjustments are implemented to the IH and DH samples with respect to the reference building according to the TS 825 standard. Since the heating load have a proportional relation with U-value, exterior wall area and the differences between the outer temperature for design and inner temperature for thermal comfort, proportional adjustments are executed on these parameters.

13) After augmentations and adjustments, the samples are compared with their adjusted natural gas consumptions per unit areas.

14) According to the adjusted data, carbon emissions for unit area are calculated to compare the sample buildings.

15) By using the company's database, total residential area in Bursa is calculated according to the Number of Detached Section (BBS) approach of EMRA. The linkage between the BBS and the real net residential area is supported by the statistical assignments according to the analysis of the company officials.

16) Total residential natural gas consumption and related carbon emissions are calculated for the buildings that are heated by IH, CH and DH systems.

17) Six different projection scenarios based on different combinations of heating systems are developed for Bursa's residential sector

18) Citywide energy saving and carbon mitigation potential of each scenario is calculated.

5.2. Research Findings

During the research, it is realized that DH system is used very uncommonly in Bursa. That is why the company's database does not have a separated division for DH system. It can be found only in CH system division, which includes CH and DH system users together on the same database. However, according to the field research, we found out that very small portion of residential natural gas consumers in Bursa prefer DH system. It can be seen that 93,5% of subscribers of BURSAGAZ is heated by IH system where this rate is 4,76% for CH and only 1,62% for DH systems, as shown in Table 5.1 and Figure 5.1.

Table 5.1. Heating System Ranges for Residential Natural Gas Consumers in Bursa

	Total Area (m^2)	Area Rate	Number of Subscribers	Subscribers Rate
IH	96.219.307,75	89,527%	531.070,00	93,547%
CH	8.191.944,50	7,622%	27.029,00	4,761%
DH	3.063.337,75	2,850%	9.607,00	1,692%
TOTAL	107.474.590,00		567.706,00	

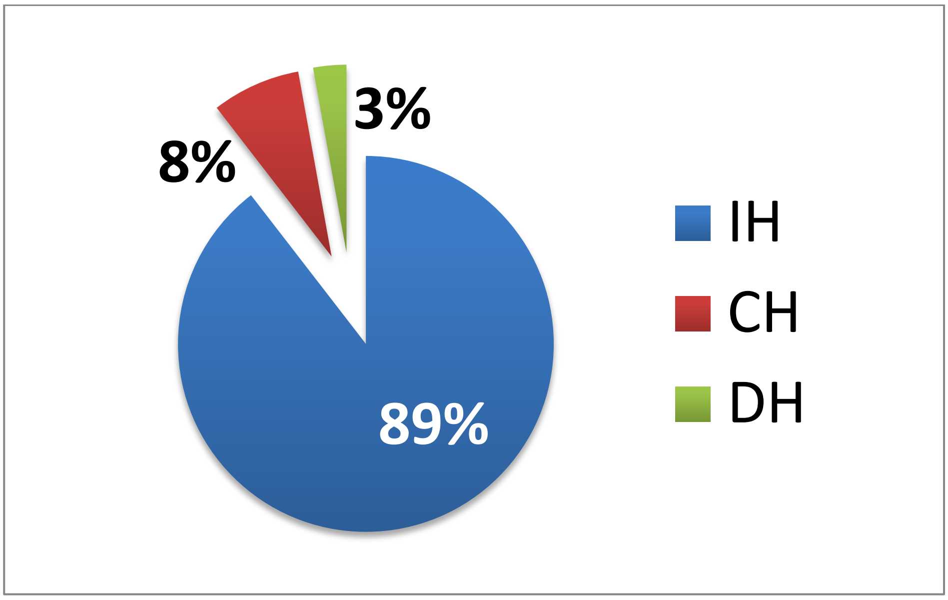

Figure 5.1. Heating system ranges for residential heated areas in Bursa

Natural gas consumption and related CO_2 emissions per unit area are calculated according to the methodology developed in this research for each different heating system. Since carbon emissions are calculated by multiplying the natural gas consumption amount with the IPCC emission factor, the reduction rates of energy consumption and carbon emission appear as same. Therefore, total residential natural gas consumption and related CO_2 emissions of Bursa at present are calculated by using the methodology as the baseline scenario. Results of the baseline scenario can be seen on Table 5.2 and Figure 5.2.

Table 5.2. Residential Natural Gas Consumption and Carbon Emissions of Bursa City

Heating Systems	Total Urban Residential Area (m^2)	Natural Gas Consumption per unit area (Sm^3/m^2)	Total Natural Gas Consumption (Sm^3)	CO_2 Emissions per unit area ($kgCO_2/m^2$)	Total CO_2 Emissions ($kgCO_2$)
IH	96.219.308	5,75	552.972.367	12,35	1.188.779.983
CH	8.191.945	4,92	40.263.407	10,57	86.558.273
DH	3.063.338	4,36	13.368.406	9,38	28.739.399
TOTAL	107.474.590		606.604.175		1.304.077.655

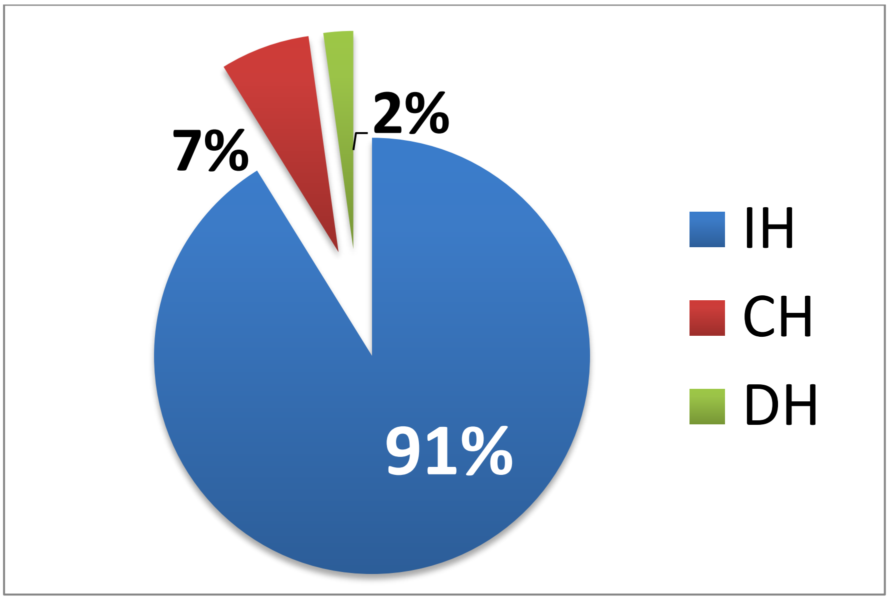

Figure 5.2. Ranges for residential natural gas consumption and CO_2 emissions in Bursa

The unit area natural gas consumption and carbon emissions of sample buildings show that the most efficient residential heating system is DH system and the least efficient one is the IH system. When total rates of different systems are considered in terms of heated areas it is obvious that there are remarkable differences between IH system's consumptions and emissions compared to the CH and DH systems. This can be considered as one of the most significant point as a policy-making argument. In more concrete terms, the use of CH and DH systems should be preferred against the IH systems, and especially for new building constructions, installations of IH systems should be discouraged.

The projection scenarios provide supportive results for this policy implication. We found out that if IH systems are replaced with CH and DH systems, significant savings in energy consumption and remarkable reduction in CO_2 emissions could be achieved. For instance; if 40% of the existing IH systems are replaced with CH systems, a citywide energy saving of 32.021.785 Sm^3 per year and 5.3% reduction in CO_2 emissions could be achieved. If a more ambitious scenario is followed and all of the existing IH systems are replaced with CH systems in Bursa, 13% reduction in both natural gas use and associated carbon emissions could be achieved.

These amounts of energy savings stated as natural gas in terms of standard volume have also a significant financial aspect. In addition to the externalities and related multiplier effects for energy market, national budget and end use economies can receive significant financial benefits from such energy savings. Since the prices of imported gas is confidential with international trade agreements, financial benefits can only be estimated by using the EMRA tariffs. By this scope, with the estimated natural gas prices of 2014, 13% reduction in natural gas use in residential sector could correspond to monetary savings of 25.649.449TL per year (around $9 million/year) in total natural gas import budget. Furthermore, according to 2014 residential tariff of Bursa, reducing natural gas consumption in Bursa by

32.021.785Sm^3 in a year would lead to monetary savings of 35.714.067TL per annum (around $12 million/year) for residential consumers.

Although there are substantial economic benefits in transition to central or district heating systems, such a policy shift is not very easy to achieve in Turkey because of some cultural barriers. We expect that users of IH systems would be reluctant to replace IH systems with CH or DH ones. As the IH users feel free to switch on or switch off the heating system anytime they like, they usually think that IH systems are more cost-effective. In order to overcome such cultural barriers, existing regulations could be supported by social and economical incentives to encourage IH users. On the other hand, further research is required to understand the extent of the cultural barriers and to develop policies and strategies to overcome them.

Furthermore, the projections indicate that the differences between DH and CH systems are very limited. When this finding is considered with the Rational Exergy Management Model the importance of the cogeneration becomes apparent especially for DH systems. Since total amount of natural gas consumed by the DH system is remarkably bigger than other systems and the settling organization of DH system needs a separated center for boiling equipment the cogeneration systems can be considered as an improving argument for DH system implementations.

5.3. Future Research and Restrictions

It should be emphasized that there are several difficulties to achieve reliable database for actual energy consumption of real house dwellers. It is considered as important to highlight the restrictions that should be improved for further studies by using a similar methodology.

The main restrictions are realized while selecting reliable samples and collecting data. To obtain better comparison results in order to predict citywide consumption level, number of sub samples should be extended. Selected samples for each heating system could be distributed to different parts of city to be able to distribute the end use profiles on different social, cultural and economic consumer groups. For instance in Bursa, not only Nilüfer Municipality but also other central municipalities can be included to a further study. Therefore, by using the same methodology on different groups of samples we could explore the diversity of residential energy end-use groups in terms of physical effects related to climatically variations or constructional dissimilarities and social effects such as cultural and economical differences.

If the number of sample groups will be increased for more localities in the city, climatic zones could be defined and climatic diversions can be better represented on the selected samples. These samples could be selected in a constructional perspective to provide better resolutions on the parameters such as U-value, shape of building, thermal comfort conditions that are directly effects the residential natural gas consumptions.

Another resolution problem can be observed on combustion efficiencies of the boilers. An extension from natural gas consumption of residential samples to the citywide carbon emission includes an assumption related with the combustion efficiencies of the each of the boilers using in the city. Although this is one of the most uncertain parts of the study, this can also be handled with increased number of samples included into the comparison methodology.

Another resolution problem is regarding to the area calculations. As it is discussed in the last part of methodology chapter, citywide residential area is calculated by using BBS approach of EMRA regulation. Since BBS approach is used for just to determine the price of subscriptions in natural gas distribution companies in Turkey, this is recorded as an important data on companies' database. However, since natural gas consumption is essential for comparative research, the area based on interior installation projects are taken into the account. To be able to implement a better linkage between comparison methodology and citywide consumption calculations, areas based on installations should be used in both parts of the study. A regulation proposal could be enhanced leading to better residential area records on the databases of natural gas distribution companies.

On the other hand, to be able to understand the possible effects of micro-cogeneration and cogeneration implementations on the residential heating systems, some new projections can be investigated with similar data considering the perspective of Rational Exergy Management Model such as the Projected Scenario 7 shown in Appendix C. Considering both consumptions and emissions of samples and citywide projections a better policy making argument can be calculated by using the methodology executed for this study.

An additional advantage of cogeneration implementation on DH system can be mentioned with regard to the tariff methodology of natural gas distribution market. Since investments of companies are reflected to the tariff of all natural gas consumers in the distribution region, cogeneration implementations would provide a cheaper end use especially for low-income households in urban peripheries. That is why for future research, neighborhoods located in peripheries could be also investigated with samples selected from those areas.

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APPENDIX A

BUILDING DEFINITION FORM
USED IN THE FIRST FIELD RESEARCH

BİNA/KONUT ISITMA SİSTEMLERİ BİLGİ FORMU				
Bina Tespit Bilgileri				
İlçe:	**Semt:**	**Mh:**	**Cd/Sk:**	**No:**
Apt:	**Abone No:**	**ISITMA SİSTEMİ**		
		Bireysel	**Merkezi**	**Bölgesel**

Bina Enerji Kimlik Verileri		
Yapı Türü:	**Bina Yaşı:**	**Daire Sayısı:**
Bina Alanı (m^2):	**Daire Alanı:**	**Isıtılan Alanlar(m^2):**
EVF:	**Bina Enerji Yöneticisi:**	**Enerji Kimlik Belgesi:**
Yalıtım Durumu:	**Yalıtım Tarihi:**	
Yalıtım Kapsamı:		

Duvarlar	Pencereler	Balkon	Çatı

Yalıtım Projesi:	**Kazan Yaşı:**	**Kazan Projesi:**

Bina Kullanıcı Profili				
Aile Sayısı	Yalnız Yaşanan Daire Sayısı			
0-3 Yaş Nüfusu				

APPENDIX B

DATA, CALCULATIONS AND RESULTS FOR COMPARISON AND PROJECTION SCENARIOS

Samples	Kitchen Use	Water Heating	Num. of Apartments	Area of an Apartment (m2)	Area based Installation (m2)	Num. of Floors	Avg. Rential Value (TL)	Avg. Sale Value (TL)	Age of Building
IH	Kombi (NG)	Kombi (NG)	15	125	125*15=1875	5	800	150000	15
CH	Individual (LPG)	Central (NG)	30	140	4688	8	800-1000	250000	3
DH	Ind. (Electricity)	District (NG)	76 Apt * 7 Blocks	300-220-180	115500	18	1500-1700	500000	10

TS 825 BİNA U DEĞERLERİ HESABI

Proje Adı:	Örnek Proje	Revizyon:	1
Hesaplayan:	Hesaplayan	Tarih:	16/07/15
Kontrol:	Kontrol Eden		

Yapıldığı Yer	Dış Sıcaklık	Rüzgar Durumu	İşletme Durumu
BURSA	-6 °C	Rüzgarlı	2. İşletme

Açıklama	İşaret	Binadaki Yapı Elemanları	Yapı elemanı kalınlığı m	Isı iletkenlik hesap değeri lh	Isı iletkenlik direnci R W/mK	Isı geçirgenlik katsayısı U W/m²K
Dış Duvar	Dd2	Ri, Yüzeysel Isıl İletim Katsayısı (iç)			0,130	
		(4.3) Alçı harcı, kireçli alçı harcı	0,010	0,700	0,014	
		(4.6) Çimento harçlı şap	0,020	1,400	0,014	
		(7.1.5.2) Yatay delikli tuğlalarla yapılan duvarlar (TS EN 771-1)	0,150	0,360	0,417	
		(10.3.2.1.1) Ekstrüde polistren köpüğü - TS 11989 EN 13164'e uygun ısı iletkenlik grupları 030	0,010	0,030	0,333	
		(4.6) Çimento harçlı şap	0,020	1,400	0,014	
		Re, Yüzeysel Isıl İletim Katsayısı (dış)			0,040	
TEKIL ISITMA (IH)		**TOPLAM**	**0,210**		**0,962**	1,040

Açıklama	İşaret	Binadaki Yapı Elemanları	Yapı elemanı kalınlığı m	Isı iletkenlik hesap değeri lh	Isı iletkenlik direnci R W/mK	Isı geçirgenlik katsayısı U W/m²K
Dış Duvar	Dd4	Ri, Yüzeysel Isıl İletim Katsayısı (iç)			0,130	
		(4.3) Alçı harcı, kireçli alçı harcı	0,020	0,700	0,029	
		(6.1.1.3) Normal derz kalınlığında ve normal harçla yerleştirilen levhalar	0,190	0,240	0,792	
		(10.3.2.1.3) Ekstrüde polistren köpüğü - TS 11989 EN 13164'e uygun ısı iletkenlik grupları 040	0,025	0,040	0,625	
		(4.2) Çimento harcı	0,020	1,600	0,013	
		Re, Yüzeysel Isıl İletim Katsayısı (dış)			0,040	
MERKEZI ISITMA (CH)		**TOPLAM**	**0,255**		**1,628**	0,614

Açıklama	İşaret	Binadaki Yapı Elemanları	Yapı elemanı kalınlığı m	Isı iletkenlik hesap değeri lh	Isı iletkenlik direnci R W/mK	Isı geçirgenlik katsayısı U W/m²K
Dış Duvar	Dd5	Ri, Yüzeysel Isıl İletim Katsayısı (iç)			0,130	
		(4.3) Alçı harcı, kireçli alçı harcı	0,020	0,700	0,029	
		(6.2.4) Hafif betondan duvar plakları	0,120	0,470	0,255	
		(10.3.1.1.4) Polistiren - Partiküler köpük - TS 7316 EN 13163'e uygun ısı iletkenlik grupları 040	0,030	0,040	0,750	
		(4.2) Çimento harcı	0,020	1,600	0,013	
		Re, Yüzeysel Isıl İletim Katsayısı (dış)			0,040	
BOLGESEL ISITMA (DH)		**TOPLAM**	**0,190**		**1,216**	0,822

Heating System Samples	Final Consumer	Monthly Natural Gas Consumption for 2014 (Sm^3)												Consumption for 2014 (Sm3)
		1	2	3	4	5	6	7	8	9	10	11	12	
IH	1	413,59	163,02	226,07	222,29	65,9	39,94				56,6	49,96	176,53	1413,9
	2	380,59	249,21	197,04	215,08	31,43	16,98			56,47	17,68	54,95	144,25	1363,68
	3	222,78	146,41	104,74	114,23	51,71	17,97			20,45	54,03	91,92	150,35	974,59
	4	308,39	181,71	170,07	142,02	70,97	30,96			42,84	22,59	93,92	215,36	1278,83
	5	250,63	156,79	132,74	57,63					52,75	43,22	138,88	221,46	1054,1
	6	348,61	273,09	210,52	185,24	40,56	25,96			73,02	24,56	56,95	160,51	1399,02
	7	301,17	224,29	105,78	76,15	47,65	18,97			25,32	15,72	28,97	116,82	960,84
	8	182,56	144,33	95,41	97,77	54,75	31,95			60,37	28,49	45,96	44,7	786,29
	9	280,54	218,06	178,37	177,01	97,34	44,94			72,05	29,47	89,92	128	1315,7
	10	317,67	235,71	203,26	181,12	39,54	26,96			79,84	17,68	73,94	189,97	1365,69
	11	344,49	252,32	229,19	151,28	21,29	23,97			63,29	23,58	70,94	212,31	1392,66
	12	356,86	209,75	191,85	178,04	88,21	38,94			47,71	16,7	55,95	209,27	1393,28
	13	217,63	122,53	78,82	73,07		18,12					38,22	102,6	650,99
	14	341,38	252,32	174,22	173,92	73	56,92			149,94	64,83	64,94	164,56	1516,03
	15	213,5	84,11	101,63	94,68	3,04				36,28	43,61	72,34	135,23	784,42
	TOTAL	4480,39	2913,65	2399,71	2139,53	685,39	392,58	0	0	780,33	458,76	1027,76	2371,92	17650,02
CH	C-Block	5.281,09	3.451,21	2.793,04	2.542,70	1.586,76	981,77		1.353,25	603,55	751,57	1.170,84	2.524,90	23.040,68
DH	Site	133250,36	119161,24	112262,13	57506,18	34260,05	21449,72	21971,6	20992,95	22506,74	47051,54	111.713,42	185.654,00	887779,93

Heating System Samples	Final Consumer	Monthly Natural Gas Consumption for 2014 (Sm^3)												Consumption for 2014 (Sm3)	Combustion Efficiency	Combusted Amount of NG (Sm3)	Emissions (KgCO2)	Total Interior Area (m2)	U values (W/m2K)
		1	2	3	4	5	6	7	8	9	10	11	12						
IH	1	413,59	163,02	226,07	222,29	65,9	39,94				56,6	49,96	176,53	1413,9	0,92	1300,788	2447,51786	125	
	2	380,59	249,21	197,04	215,08	31,43	16,98			56,47	17,68	54,95	144,25	1363,68	0,9	1227,312	2638,7208	125	
	3	222,78	146,41	104,74	114,23	51,71	17,97			20,45	54,03	91,92	150,35	974,59	0,9	877,131	1885,83165	125	
	4	308,39	181,71	170,07	142,02	70,97	30,96			42,84	22,59	93,92	215,36	1278,83	0,92	1176,5236	2529,52574	125	
	5	250,63	156,79	132,74	57,63					52,75	43,22	138,88	221,46	1054,1	0,91	959,231	2062,34665	125	
	6	348,61	273,09	210,52	185,24	40,56	25,96			73,02	24,56	56,95	160,51	1399,02	0,933	1305,28566	2806,364169	125	
	7	301,17	224,29	105,78	76,15	47,65	18,97			25,32	15,72	28,97	116,82	960,84	0,92	883,9728	1900,54152	125	
	8	182,56	144,33	95,41	97,77	54,75	31,95			60,37	28,49	45,96	44,7	786,29	0,91	715,5239	1538,376385	125	
	9	280,54	218,06	178,37	177,01	97,34	44,94			72,05	29,47	89,92	128	1315,7	0,91	1197,287	2574,16705	125	
	10	317,67	235,71	203,26	181,12	39,54	26,96			79,84	17,68	73,94	189,97	1365,69	0,9	1229,121	2642,61015	125	
	11	344,49	252,32	229,19	151,28	21,29	23,97			63,29	23,58	70,94	212,31	1392,66	0,91	1267,3206	2724,73929	125	
	12	356,86	209,75	191,85	178,04	88,21	38,94			47,71	16,7	55,95	209,27	1393,28	0,93	1295,7504	2785,86336	125	
	13	217,63	122,53	78,82	73,07		18,12					38,22	102,6	650,99	0,9	585,891	1259,66565	125	
	14	341,38	252,32	174,22	173,92	73	56,92			149,94	64,83	64,94	164,56	1516,03	0,91	1379,5873	2966,112695	125	
	15	213,5	84,11	101,63	94,68	3,04				36,28	43,61	72,34	135,23	784,42	0,92	721,6664	982,98688	125	
	TOTAL	4480,39	2913,65	2399,71	2139,53	685,39	392,58	0	0	780,33	458,76	1027,76	2371,92	17650,02	0,913		33745,36985	1875	1,04
CH	C-Block	5.281,09	3.451,21	2.793,04	2.542,70	1.586,76	981,77		1.353,25	603,55	751,57	1.170,84	2.524,90	23.040,68	0,93	21.427,83	46.069,84	4.688,00	0,61
DH	Site	133250,36	119161,24	112262,13	57506,18	34260,05	21449,72	21971,6	20992,95	22506,74	47051,54	111.713,42	185.654,00	887779,93	0,925	821196,4353	1765572,336	139230	0,82

		IH	CH	DH
	Area for an Apartment	125	146,5	210
	Number of Floors for a Building	5	8	18
	Number of Apartments in a Floor	3	4	4
	Area for a Floor	375	586	917
	Total Area based Interior Installation	1875	4688	16500
	Total Annual NG Consumption (2014)	17186	23040	126825
Real Values	NG Consumtion for a Floor	3437,2	2880	7045,833
	NG Consumption per Unit Area	9,165867	4,914676	7,68357
Augmented Values	Augumented Number of Floors	5,15	8,45	19,75
	NG Consumption for the 1st Floor	3337,087	2726,627	6421,519
	NG Cons. per Unit Area of 1st Floor	8,8989	4,652947	7,002747

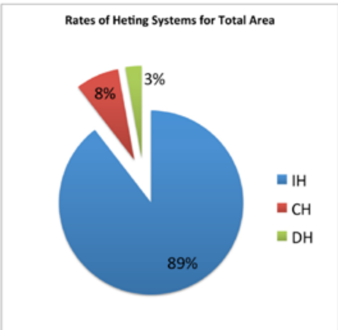
q=UA(Ti-To)	Exterior Wall Area (m2)	Inner Air Temp, Ti (°C)	Outer Temp, To (°C)	Ti-To (K)	U Value (W/m2K)	Floor Area (m2)	Total Area (m2)	Combustion Efficiency
IH	286	22	-6	28	1,040	375	1875	0,913
CH	286	23	-6	29	0,614	586	4688	0,93
DH	350	24	-6	30	0,822	917	16500	0,925

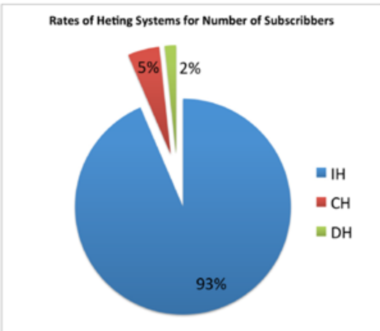
	HEATING LOAD CALCULATİONS BY NG CONSUMPTIONS (Sm3)					
Floor No	for Reel Number of Floors			for Adjusted Number of Floors (8)		
	IH	CH	DH	IH	CH	DH
18			9,556			
17			9,174			
16			9,174			
15			9,174			
14			8,791			
13			8,791			
12			8,791			
11			8,409			
10			8,409			
9			8,409			
8		5,351	8,027	10,234	5,351	8,791
7		5,118	8,027	9,789	5,118	8,409
6		5,118	8,027	9,789	5,118	8,409
5	9,789	4,886	7,645	9,344	4,886	8,027
4	9,344	4,886	7,645	9,344	4,886	8,027
3	8,899	4,653	7,645	8,899	4,653	7,645
2	8,899	4,653	7,645	8,899	4,653	7,645
1	8,899	4,653	7,645	8,899	4,653	7,645
Consumption per Unit Area for total Number of Floors (Sm3/m2)	**45,829**	**39,317**	**150,982**	**75,196**	**39,317**	**64,597**
Average Consumptions for Augmented Foor (Sm3/m2)	**9,166**	**4,915**	**8,388**	**9,399**	**4,915**	**8,075**
Total NG Consumption (Sm3)	**17186,000**	**23040,000**	**126825,000**	**44064,682**	**23040,000**	**37854,090**
NG with Adjustments for Exterior Wall Area (Sm3)				44064,682	23040,000	30932,199
NG with Adjustments for Inner Air Temperature (Sm3)				45638,420	23040,000	29901,126
NG with Adjustments for U Values (Sm3)				26944,221	23040,000	22334,904
Augmented and Adjusted Values	**NG Consumption for Unit Area (Sm3/m2)**			**5,747**	**4,915**	**4,764**
	Total CO2 Emissions for Sampels (kgCO2)			**52890,159**	**46068,480**	**44418,541**
	CO2 Emissions per Unit Area (kgCO2/m2)			**11,282**	**9,827**	**9,475**
	Energy Consumption for Samples (kWh)			**286686,513**	**245145,600**	**237643,381**
	Energy Consumption per Unit Area (kWh/m2)			**61,153**	**52,292**	**50,692**

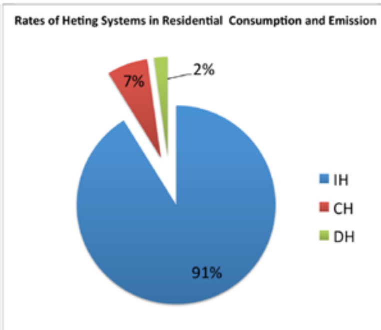
	IH	CH	DH
Number of Consumers	531.070,00	27.029,00	9.607,00
Number of Total BBS	658.527,00	48.111,00	17.772,00
Number of 2nd BBS	127.457,00	21.082,00	8.165,00

1st BBS		IH SYSTEM		CH SYSTEM		DH SYSTEM	
Area (m2)	**Ranges**	**1st BBS**	**Area (m2)**	**1st BBS**	**Area (m2)**	**1st BBS**	**Area (m2)**
75,00	0,10	53.107,00	3.983.025,00	2.702,90	202.717,50	960,70	72.052,50
100,00	0,30	159.321,00	15.932.100,00	8.108,70	810.870,00	2.882,10	288.210,00
125,00	0,39	207.117,30	25.889.662,50	10.541,31	1.317.663,75	3.746,73	468.341,25
150,00	0,25	132.767,50	19.915.125,00	6.757,25	1.013.587,50	2.401,75	360.262,50
175,00	0,05	26.553,50	4.646.862,50	1.351,45	236.503,75	480,35	84.061,25
200,00	0,01	5.310,70	1.062.140,00	270,29	54.058,00	96,07	19.214,00
Total	1,00	531.070,00	**67.445.890,00**	27.029,00	**3.432.683,00**	9.607,00	**1.220.089,00**
2nd BBS		**IH SYSTEM**		**CH SYSTEM**		**DH SYSTEM**	
200 + Area (m2)	**Ranges**	**2nd BBS**	**Area (m2)**	**2nd BBS**	**Area (m2)**	**2nd BBS**	**Area (m2)**
10,00	0,40	50.982,80	509.828,00	8.432,80	84.328,00	3.266,00	32.660,00
25,00	0,40	50.982,80	1.274.570,00	8.432,80	210.820,00	3.266,00	81.650,00
50,00	0,14	17.843,98	892.199,00	2.951,48	147.574,00	1.143,10	57.155,00
75,00	0,05	6.372,85	477.963,75	1.054,10	79.057,50	408,25	30.618,75
100,00	0,01	1.274,57	127.457,00	210,82	21.082,00	81,65	8.165,00
Total	1,00	127.457,00	**3.282.017,75**	21.082,00	**542.861,50**	8.165,00	**210.248,75**
200*BBS2			**25.491.400,00**		**4.216.400,00**		**1.633.000,00**
TOTAL AREA		**96.219.307,75**		**8.191.944,50**		**3.063.337,75**	
		IH SYSTEM		**CH SYSTEM**		**DH SYSTEM**	

				Total Area for Bursa (m2)	NG Consumption per Unit Area (Sm3/m2)	NG Consumption for Bursa (Sm3)	CO2 Emission per Unit Area (kgCO2/m2)	CO2 Emission or Bursa (kgCO2)	NG Consumption Relative to Existing Condition (Sm3)	CO2 Emission Relative to Existing Condition (kgCO2)
EXISTING CONDITIONS			IH	96.219.307,75	5,75	552.972.361,64	12,35	1.188.779.983,05	-	-
			CH	8.191.944,50	4,92	40.263.407,22	10,57	86.558.272,84	-	-
			DH	3.063.337,75	4,36	13.368.405,94	9,38	28.739.399,09	-	-
			TOTAL	107.474.590,00		606.604.174,80		1.304.077.654,98	-	-
Projection 1	IH to CH	0	IH	96.219.307,75	5,75	552.972.361,64	12,35	1.188.779.983,05	-	-
	CH to DH	0,4	CH	4.915.166,70	4,92	24.158.044,33	10,57	51.934.963,70	16.105.362,89	34.623.309,13
	IH to DH	0	DH	6.340.115,55	4,36	27.668.264,26	9,38	59.481.234,51	- 14.299.858,32	- 30.741.835,41
			TOTAL	107.474.590,00		604.798.670,23		1.300.196.181,26	1.805.504,57	3.881.473,72
			MITTIGATION	0,000%		0,298%		0,298%		
Projection 2	IH to CH	0,4	IH	57.731.584,65	5,75	331.783.416,98	12,35	713.267.989,83	221.188.944,66	475.511.993,22
	CH to DH	0	CH	46.679.667,60	4,92	229.430.566,25	10,57	493.229.831,33	- 189.167.159,04	- 406.671.558,50
	IH to DH	0	DH	3.063.337,75	4,36	13.368.405,94	9,38	28.739.399,09	-	-
			TOTAL	107.474.590,00		574.582.389,18		1.235.237.220,26	32.021.785,62	68.840.434,72
			MITTIGATION	0,000%		5,279%		5,279%		
Projection 3	IH to CH	0,4	IH	57.731.584,65	5,75	331.783.416,98	12,35	713.267.989,83	221.188.944,66	475.511.993,22
	CH to DH	0,4	CH	43.402.889,80	4,92	213.325.203,37	10,57	458.606.522,20	- 173.061.796,15	- 372.048.249,36
	IH to DH	0	DH	6.340.115,55	4,36	27.668.264,26	9,38	59.481.234,51	- 14.299.858,32	- 30.741.835,41
			TOTAL	107.474.590,00		572.776.884,61		1.231.355.746,54	33.827.290,19	72.721.908,44
			MITTIGATION	0,000%		5,577%		5,577%		
Projection 4	IH to CH	1	IH	-	5,75	-	12,35	-	552.972.361,64	1.188.779.983,05
	CH to DH	0	CH	104.411.252,25	4,92	513.181.304,81	10,57	1.103.237.169,08	- 472.917.897,59	- 1.016.678.896,24
	IH to DH	0	DH	3.063.337,75	4,36	13.368.405,94	9,38	28.739.399,09	-	-
			TOTAL	107.474.590,00		526.549.710,75		1.131.976.568,17	80.054.464,05	172.101.086,81
			MITTIGATION	0,000%		13,197%		13,197%		
Projection 5	IH to CH	1	IH	-	5,75	-	12,35	-	552.972.361,64	1.188.779.983,05
	CH to DH	0,5	CH	100.315.280,00	4,92	493.049.601,20	10,57	1.059.958.032,66	- 452.786.193,98	- 973.399.759,82
	IH to DH	0	DH	7.159.310,00	4,36	31.243.228,84	9,38	67.166.693,36	- 17.874.822,90	- 38.427.294,27
			TOTAL	107.474.590,00		524.292.830,04		1.127.124.726,02	82.311.344,76	176.952.928,96
			MITTIGATION	0,000%		13,569%		13,569%		
Projection 6	IH to CH	0	IH	-	5,75	-	12,35	-	552.972.361,64	1.188.779.983,05
	CH to DH	1	CH	-	4,92	-	10,57	-	40.263.407,22	86.558.272,84
	IH to DH	1	DH	107.474.590,00	4,36	469.019.110,76	9,38	1.008.297.284,31	- 455.650.704,82	- 979.557.885,22
			TOTAL	107.474.590,00		469.019.110,76		1.008.297.284,31	137.585.064,04	295.780.370,67
			MITTIGATION	0,000%		22,681%		22,681%		
Projection 7 COGENERATION CASE	IH to CH	0	IH	-	5,75	-	12,35	-	552.972.361,64	1.188.779.983,05
	CH to DH	1	CH	-	4,92	-	10,57	-	40.263.407,22	86.558.272,84
	IH to DH	1	DH without COG	107.474.590,00	4,36	469.019.110,76	9,38	1.008.297.284,31	- 455.650.704,82	- 979.557.885,22
			DH with COGEN	-	-	178.227.262,09		383.188.613,49	290.791.848,67	625.108.670,82
			TOTAL	107.474.590,00		178.227.262,09		383.188.613,49	428.376.912,71	920.889.041,49
			MITTIGATION	0,000%		29,381%		29,384%		







	Total Area(m2)	Area Rate	Number of Subscribbers	Subscribbers Rate	NG Consumption per Unit Area (Sm3/m2)	NG Consumption for Bursa (Sm3)	Consumption and Emision Rates	CO2 Emission per Unit Area (kgCO2/m2)	CO2 Emission or Bursa (kgCO2)
IH	96.219.307,75	89,527%	531.070,00	93,547%	5,75	552.972.361,64	91,159%	12,35	1.188.779.983,05
CH	8.191.944,50	7,622%	27.029,00	4,761%	4,92	40.263.407,22	6,638%	10,57	86.558.272,84
DH	3.063.337,75	2,850%	9.607,00	1,692%	4,36	13.368.405,94	2,204%	9,38	28.739.399,09
TOTAL	107.474.590,00		567.706,00			606.604.174,80			1.304.077.654,98

APPENDIX 3

COGENERATION CASE,
RATIONAL EXERGY MANAGEMENT MODEL
CALCULATIONS AND RESULTS

Figure C.1. The Cogeneration Process

The amount of electricity production of the cogeneration is notified by E in Figure C.1. The amount of useful heat production of cogeneration is denoted by H (calculated for this purpose as total heat production minus any heat produced in separate boilers or by live steam extraction from the steam generator before the turbine) (EU, 2004).

$$\mathrm{E} = \mathrm{H} \times C \tag{1a}$$

Here C, shown in Equation 1a, is the power-to-heat ratio of cogeneration. It can be selected from default values given in Table C.1. In this study, C is selected as 0.75 (EU. 2004), (Kılkış B., 2007-b).

Table C.1. Default power to heat ratio according to the type of generation unit

Type of the unit	**Default power to heat ratio,** *C*
Combined cycle gas turbine with heat recovery	0.95
Steam back pressure turbine	0.45
Steam condensisng extraction turbine	0.45
Gas turbine with heat recovery	0.55
Internal combustion engine	0.75

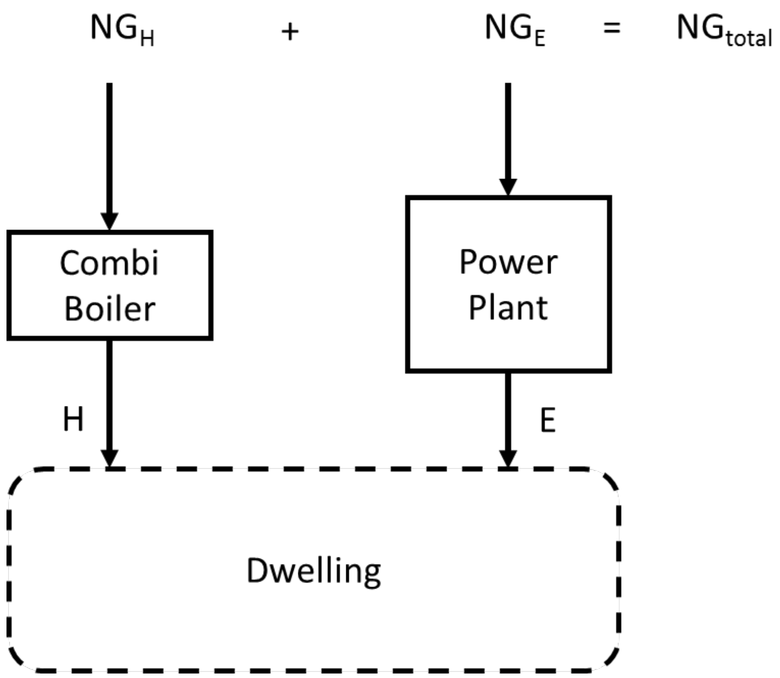


Figure C.2. Power and heat supply schematics for Projections 1-6

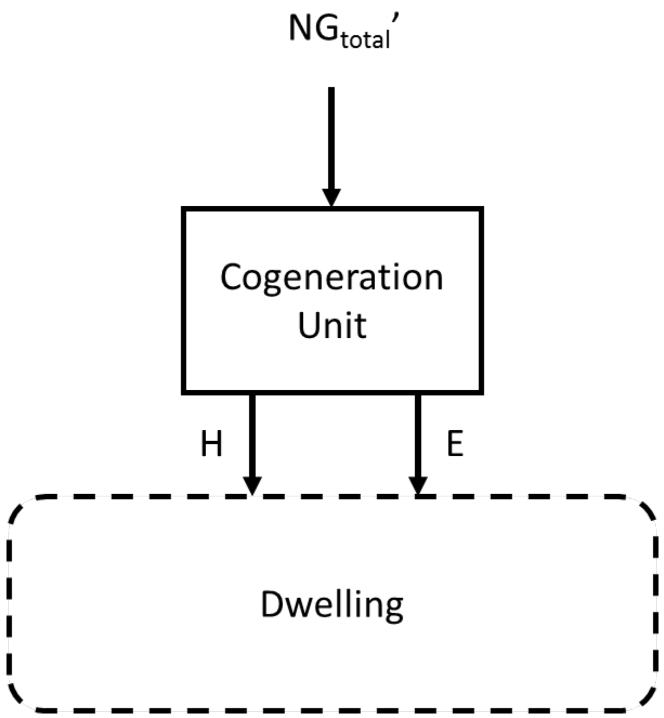


Figure C.3. Power and heat supply schematics for Projection 7

Figure C.2 and Figure C.3 show power and heat supply schematics for Projection Scenarios 1-6 and Projection Scenario 7 respectively. Total natural gas (NG) consumption amounts of Projections 1-6 can be calculated by using Equation 2a. If electricity demand would be supplied by the cogeneration unit, NG_E can be considered as zero (Kilkis, S., 2007). This is because, 59 % of total amount of natural gas is used in electricity generation in Turkey and this rate is 21% for end use of residential heating. %48 of total electricity generation is based on natural gas on the other hand (Evren, N. E. 2015). Thus, in new case, NG'_{total} supply both electricity load and heating load. Natural gas consumption for heating demand calculated with Equation 3a.

$$NG_{total} = NG_H + NG_E \text{ ….. (For Projections 1-6)} \tag{2a}$$

$$NG'_{total} = NG'_H + NG'_E \text{ ….. (For Projection 7)} \tag{3a}$$

Natural gas consumption for heating is calculated below with using Equation 3a:

$$NG'_H = NG'_{total} - NG'_E$$

$$NG'_H = \frac{\mathrm{H}}{\eta_H} - \frac{\mathrm{E}}{\eta\_E}$$

Here *E* can be written in terms of of *H* by using Equation 1a:

$$NG'_H = \frac{\mathrm{H}}{\eta_H} - \frac{\mathrm{H}\ \times \mathrm{C}}{\eta_E} = H\left[\frac{1}{\eta_H} - \frac{\mathrm{C}}{\eta_E}\right]$$

Here *H* is the total NG consumption of the Projection 6, *C* is 0.75 from Table C.1, η_H is 0.55 and η_E is 0.52 (Kılkış B., 2007-b).

$$NG'_H = \mathrm{H}\left[\frac{1}{0.55} - \frac{0.75}{0.52}\right]$$

$$NG'_H = 0.38\ \mathrm{H}$$

Since the total residential natural gas consumption of Bursa is calculated as 469.019.110,76 Sm^3 for Projected Scenario 6 there is a new case that can be considered with the cogeneration system as Projected Scenario 7.

In the light of the given explanation above, for the seventh projection, total residential natural gas consumption could be calculated as %38 of the total residential natural gas consumption of Bursa is:

$$0,38 \times 469.019.110,76 = 178.227.261 \ Sm^3$$

Table C.2. Consumptions, Emissions and Mitigations for Projected Scenarios

	Existing Condition	Projection 1	Projection 2	Projection 3	Projection 4	Projection 5	Projection 6	Projection 7
Residential NG Consumption for Bursa (Sm3)	606.604.174,80	604.798.670,23	574.582.389,18	572.776.884,61	526.549.710,75	524.292.830,04	469.019.110,76	178.227.262,09
Residential CO2 Emission or Bursa (kgCO2)	1.304.077.654,98	1.300.196.181,26	1.235.237.220,26	1.231.355.746,54	1.131.976.568,17	1.127.124.726,02	1.008.297.284,31	383.188.613,49
NG Consumption Relative to Existing Condition (Sm3)	-	1.805.504,57	32.021.785,62	33.827.290,19	80.054.464,05	82.311.344,76	137.585.064,04	428.376.912,71
CO2 Emission Relative to Existing Condition (kgCO2)	-	3.881.473,72	68.840.434,72	72.721.908,44	172.101.086,81	176.952.928,96	295.780.370,67	920.889.041,49

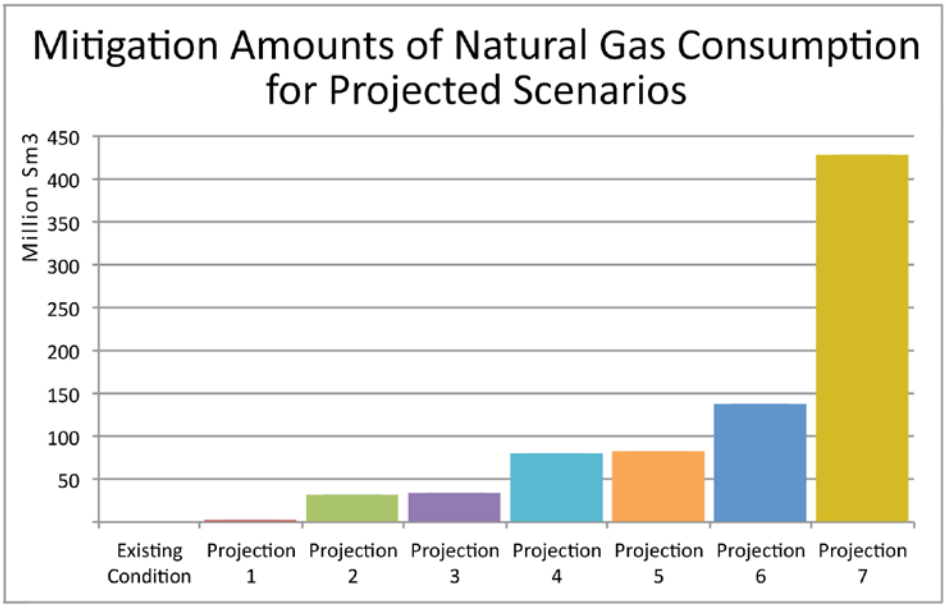


Figure C.4. Mitigation Amounts of Consumptions of Bursa for Projected Scenarios

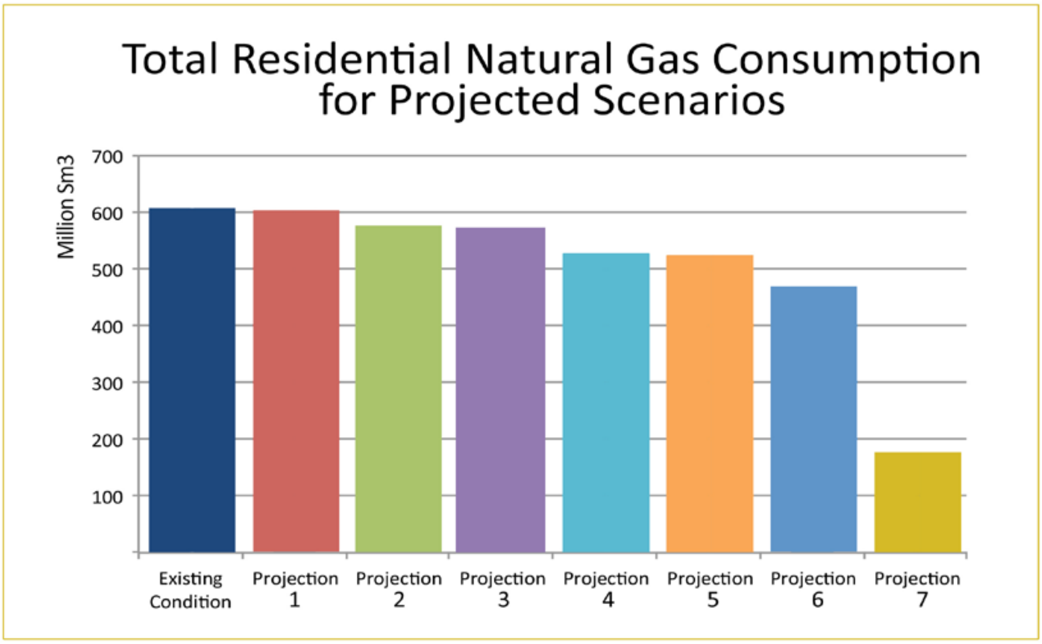


Figure C.5. Total Residendital Consumptions of Bursa for Projected Scenarios

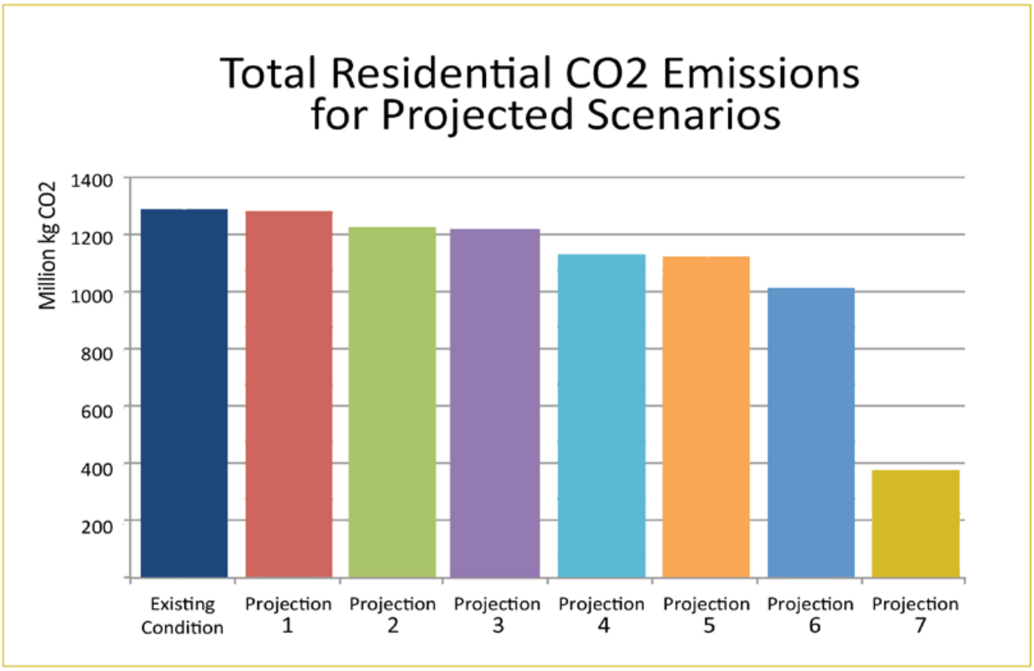


Figure C.6. Total Residendital Emissions of Bursa for Projected Scenarios

As a result, the projections 1-6 indicate that the differences between DH and CH systems are very limited. When this finding is considered with the projection 7, even the most efficient case could be improved by using Rational Exergy Management Model. With cogeneration the savings of the heating system became more than 3 times of the most efficient case without cogeneration. As is can be seen on the figures the importance of the cogeneration becomes apparent for heating systems in terms of mitigations in both natural gas consumptions and related carbon emissions. In the light of these explanations for a better policy making, cogeneration could be considered as one of the most important instruments.