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Energy Economy and Carbon Emission Potential Comparison of Heating Systems by using Multi-Criteria Decision Making Methods

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ABSTRACT

The aim of this study is to create a decision making methodology for fuel performances and greenhouse gas emissions of heating systems by considering combination of financial and non-financial criteria which are dependent on the region and the people, and to show logical choices numerically. For this purpose, a specific building with its architectural drawings was specified and heat loss equations were observed by using MS Excel according to TS 825. Calculations of heat loss were performed separately for four different types of heating zones in our country by selecting different cities in these zones. Bu using heat losses which were calculated based on placing the building in different zones, different types of heating strategies were determined. Moreover, fuel costs, installation cost and greenhouse gas emissions were determined based on different fuel usage ratios. These calculations and observed criteria were investigated by Analytical Hierarchy Process (AHP) and VIKOR, which are merged under Multi Criteria Decision Making Methods and an effort for showing the mathematical aspect of comparison of these selections was given in this study.

Isıtma Sistemlerinin Enerji Ekonomileri ve Karbon Salınım Potansiyellerinin Çok Kriterli Karar Verme Yöntemleri ile Karşılaştırılması

ÖZ

Çalışmanın amacı, bir ısıtma sistemi seçerken bölgeye ve kişisel isteklere uygun, finansal ve finansal olmayan kriterleri bir arada değerlendirerek, yakıt performansları ve sera gazı salınımı özelinde bir karar verme metadolojisi oluşturmak ve mantıklı seçimleri sayısal olarak göstermektir. Bu amaçla mimari çizimi olan bir bina belirlenmiş, MS Excel kullanılarak TS 825'e uygun ısı kaybı hesabı denklemleri oluşturulmuş, ülkemizde yer alan 4 tip ısıtma bölgesi için şehirler belirlenerek ayrı ayrı hesaplanmıştır. Binanın farklı bölgelere oturtulması esasına göre yapılan ısı kayıpları kullanılarak farklı ısıtma tipleri seçimi ve farklı yakıt kullanımı üzerinden yakıt maliyeti, kurulum maliyeti ve sera gazı salınımı hesaplanmıştır. Bu hesaplamalar ve belirlenen diğer kriterler ise Çok Kriterli Karar Verme Yöntemlerinden, Analitik Hiyerarşi Prosesi (AHP) ve VIKOR ile incelenmiş, seçimlerin birbirleri ile karşılaştırılmasının matematiksel yönü ortaya konmaya çalışılmıştır.

Anahtar Kelimeler: Isıtma sistemleri, Yakıt hesabı ve sera gazı salınımı, Analitik Hiyerarşi Prosesi, VIKOR, TOPSIS

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1. Introduction

Space heating, or more generally, air conditioning has evolved due to increased prosperity in the last century. In the period until the beginning of the 20th century, the only aim of humanity is to withstand the harsh winter conditions and to warm up, while it had been started to talk about staying in thermal comfort at the end of the same century. Because of this new demand and industrial development, the energy consumption was increased, and the primary energy consumption of the world reached from 3.701,6 million TEP in 1965 to 13.511,2 million TEP in 2017 [1].

Turkey is one of the countries where energy import dependency is high. According to the given data of the General Directorate of Renewable Energy affiliated to the Ministry of Industry and Technology, the ratio of imported energy sources of primary energy use has reached 76% in recent years. Considering the same data, it was seen that primary energy consumption has reached 153 million TEP and the highest rate of consumption with 32% of the total consumption belongs to the Housing and Service sector [2].

Efficient use of energy has gained importance with the increase in energy consumption and the tendency of fossil resources to be depleted rapidly. Energy efficiency is the reduction of energy consumption per unit service or amount of product, without increasing the quality of production and quantity in industrial enterprises, while it increases the standard of living and service quality in buildings [3]. Efficiency allows to reduce emissions by improving energy security, thereby maintaining economic growth. True efficiency policy can achieve more than 40% reduction in world greenhouse gas emissions without requiring any new technology [4]. For example, in the period between 2000 and 2017, energy consumption in residences increased by 21% and reached to 120 exajoules (EJ). Thanks to the expanded energy efficiency policies, technological developments and investment trends, 14 EJ energy was saved. The effectiveness of these savings can be noticed by considering the economic growth, population and residential area increase since the beginning of the 21st century [5].

According to the research carried out by the Ministry of Energy in Turkey, it has been determined that there is a significant energy saving potential up to 30% in the energy building industry, 20% in the industrial sector and 15% in the transportation sector [6]. The 30% energy saving in the building sector can be achieved through the processes such as thermal insulation in the construction phase of the buildings in accordance with the standards (Turkish Standard 825), and the energy efficiency of the heating, cooling and lighting devices used in the residence [7]. The first major movement in the field of energy efficiency in Turkey after the TS 825, Standards of Thermal Insulation in Buildings, is the Energy Efficiency Law (ENVER) which was published in 2007 [8]. This law was followed by the "Regulation on the Sharing of Heating and Sanitary Hot Water Expenses in Central Heating and Sanitary Hot Water Systems" published in 2008 and the "Regulation on the Amendment of the Energy Performance Regulation in Buildings" published in 2010. These law and regulations aimed to use heating systems in a more efficient way depending on the size of the usage. "National Action Plan for Energy Efficiency", which was published in 2018, brought energy efficiency between 2017-2023 to forefront and aimed that "Turkey's Energy Density" (energy consumed per GDP) by 2023, should reduce at least 20% compared to 2011 [9].

One of the most important areas to take precautions to achieve this intended energy efficiency target is residential heating and the energy spent in it. It is estimated that approximately 40% of the emission arising from energy consumption worldwide is caused by the building sector [5].

Aim of the study is to emphasize the importance of efficient use of energy and to demonstrate the logical direction of heating system selection, especially under the criteria of fuel cost and greenhouse gas emissions. For this purpose, mathematical ways of decision making in engineering science have been used. At first, the Analytical Hierarchy Process (AHS) was used in criterion weighting, and the final result was obtained by using TOPSIS and VIKOR in system selection.

2. Literature Review

There are different studies in the literature where energy efficiency and multi-criteria decision making methods are discussed together;

Topoyan et al. [10] had decided using the Fuzzy AHS method to select the air conditioning system to be purchased for faculty of Economics and Administrative Sciences in Dokuz Eylül University. Four different brands were examined under the criteria of installation time, cost, cooling efficiency, heating efficiency, cooling energy cost, heating energy cost, outdoor unit sound level, indoor unit sound level and the area that the outdoor unit would occupy. As a result of the questionnaire, filled by the decision maker, the sound level of the indoor unit and the occupied area by the outdoor unit were the highest weighted criteria. Therefore, option 1 that was best result approaching to 99.25% was selected.

Chinese et al. [11] used Analytical Hierarchy Process (AHP), which is a multi-criteria decision-making method for the selection to be used in the area heating of an industrial facility. The mentioned facility is a hangar type building with a volume of approximately 15000 m3 in Treviso-Italy. Outside temperature was accepted as -5oC and heating day duration was determined as 183 days/year. Different alternatives were determined for heating such as high temperature radiant heating system, hot water air and panel heating system, low temperature wall and floor heating system. These systems were examined under 9 different criteria which are reliability, technical service support, installation time, variable resource usage possibility, suitability of the system for additions to change, thermal comfort, cost, operating cost and fuel cost. The most important criteria were operating cost and fuel cost. They concluded that the best alternative is low temperature wall and floor heating.

Ertuğrul and Aytaç [12] tried to evaluate the combi selection for a apartment in Denizli by using one of the Multi-Critical Decision Making methods, Analytical Network Process (AAS), which is a larger version of the Analytical Hierarchy Process (AHP). The criteria taken into consideration in the evaluation were brand image, customer service, after-sales service, warranty period, continuity of campaigns and campaigns, environmental impact, advertising effect and pricing, respectively. These criteria were weighted with AAS and it is concluded that the criterion with the highest weight is brand image with 37%. Brands A, B and C were successful at 78.82%, 69.72% and 78.78%, respectively.

Ertuğrul and Özçil [13] tried to make an order of preferance for A energy class air conditioners with equivalent heating and cooling capacityby using TOPSIS and VIKOR, which are multi-criteria decision making methods. The aim is to compare the methods and results by using two different multi-criteria decision making methods. When results of TOPSIS and VIKOR were compared with respect to providing acceptable advantage and acceptable stability conditions, while the results of TOPSIS method can be assorted as reliable, VIKOR method can not be assorted as reliable since required conditions for the results were not met. The best result among companies A, B, C, D, E, F, G and H, has given firm A by TOPSIS and firm C by VIKOR.

Kontu et al. [14] chose renewable energy based heating systems for the city of Loviisa-Finland under technical, economic, environmental and usage criteria suitable for use in detached houses. 11 different alternatives were evaluated under 15 different criteria by SMAA Method (The Stochastic Multicriteria Acceptability Analysis). SMAA is an extended version of AHP and is based on the superiority of the criteria with each other. As a result of the evaluation, the biomass fueled local heating system with cogeneration system producing heat and electricity gave the best result. Ground source heat pump is also accepted as the second logical choice.

Omurbek and Aksoy [15] evaluated the performance of a petroleum company, engaged in production in Turkey, between the years 2002-2014 under different criteria; such as the amount of processed crude oil, investment expenditures, production amount, sales amount, product foreign purchase (import) amount, product export (export) amount, net sales amount, operating profit and number of employees. AHP and ENTROPİ methods were used for criterion weighting; and TOPSİS and ELECTRE II were used for evaluation. The year in which the company performed best was found as 2011.

Sağır and Doğanalp [16] have set various criteria for the evaluation of energy resources. These criteria are weighted and alternatives were evaluated by fuzzy TOPSIS method. The energy sources taking into consideration for this selection are renewable energy, fossil energy and nuclear energy. Four academicians with energy expertise took part in this study as decision makers. By choosing four cost-based and eight benefit-based criteria, evaluation was made for a total of twelve criteria. Among these criteria, cost-based ones areimpact on cost, environmental impact, risk and impact on climate change. On the other hand, benefit-based criteria are reliability, reserve amount, production capacity, contribution to sustainability, support by government policies, importance for the economy of the country, simplicity and public acceptance. Renewable energy sources achieved the closest score for the perfect selection for these criteria.

Wang et al. [17] aimed to develop a methodology for decision-making, specifically for local heating systems. They used the fuzzy AHP method to make decisions for local heating systems, which have an important place in efficient heating worldwide. They developed a method based on evaluations including total of eight sub-criteria based on four main criteria.

Arslan [18] uses AHP and ORESTE methods to determine the most effective fuel type for the use of heating fuel in a public building. He choose five different criteria including calories, price, ash amount, storage, labor fees and four different alternatives as hazelnut shell, coal, fuel oil andnatural gas. While AHP method is performed through The analysis were performed by both methods and the best result was obtained for the use of natural gas fuel, which was supported by both method's results.

Yang et al. [19] conducted a study for systems used for heating purposes in Denmark. Within the framework of the Danish government's energy strategy plan by 2050, renewable energy-based systems will replace boilers where all oil and its derivatives would be used until 2035. When it was considered that approximately 205.703 houses will switch to the individual renewable energy heating system, it can be seen how major a decision will be taken in Denmark. Solar powered, heat pump sourced and biomass based systems are considered as alternatives for renewable energy-based systems. Eleven criteria have been determined in terms of economical, environmental and technological aspects, and in the light of these criteria, decisions have been made with the TOPSIS method. The best choice among the alternatives is the solar energy based system, while the heat pump is second and the biomass based system is in the third place.

Yan et al. [20] conducted a study on the heating needs of distant communities in Canada. In the examination, it was observed that petroleum and its derivatives were used as primary fuel for heating. Instead of fossil sources, the need for heating was met using three types of biomass-based combustion systems, and the results were examined by the PROMETHEE method. As a result of the examination performed under environmental, social and economical criteria, the best results were obtained in the heating system where wood based biomass was used as fuel.

3. Material and Method

The aim of this study is to create a methodology for making the most accurate heating-fuel choices in heating systems for the residential buildings in Turkey. For this purpose, in the first part of the study, the architectural design of a building that is the most common type constructed in Turkey is selected as baseline. Necessary calculations are performed through the project, that has been chosen as baseline. With this calculation, a basis has been established for the decision making process to be performed in the following parts of this study. The data obtained from the calculation are analyzed by Multi-Criteria Decision Making methods and the most appropriate choice among different alternatives is expressed.

The architectural plan, which is chosen as the main material, is a hypothetical building which is built in accordance with today's construction technique. The hypothetical building consists of an unheated basement, an entrance floor consisting of relatively smaller apartments, 11 similar upper floors and 48 flats in total.

An example apartment in the building is shown in Figure 1.

The criteria determined for the selection of a suitable heating system for this building are listed below;

1. Fuel Cost,
2. Amount of Greenhouse Gas Emission
3. Installation Cost
4. Maintenance Cost
5. Simpleness of Operation
6. Fuel Storage Status

Figure 1. Architectural appearance and acceptable temperatures for locations

The heat loss of the building whose independent areas are determined through the architectural project is calculated. According to this calculation, the associated fuel consumption is found and the fuel cost will be obtained by using the rate of fuel consumption. “Fuel Cost” is the first criterion that is used to examine the alternatives. Greenhouse gas emissions are determined based on fuel consumption calculations; therefore, "Greenhouse Gas Emissions" is the second calculated criterion. The selection of radiator and correspondingly heating system equipment and installation elements for the building, whose thermal load is calculated, are determined and the third criterion, “Installation Cost” is calculated. Marketing survey was carried out for the determination of “Maintenance Cost”, which is considered as the fourth criterion. It is determined that the annual maintenance prices would be used for “Maintenance Cost”. The fifth criterion “Fuel Storage Status” and the sixth criterion “Simpleness of Operation” are relativistic values. Thereby, these criteria weraree graded by the method used for weighting at the end of the study. These values are calculated separately for each climate zone where the hypothetical building is located.

Heating system-fuel pairs that are determined as alternatives are as follows;

1. Natural Gas-Combi Boiler (Individual System) A1
2. Natural Gas-Boiler (Central Heating System) A2
3. Fuel Oil-Boiler (Central Heating System) A3
4. Coal-Boiler (Central Heating System) (Three different types of coal) A4, A5, A6
5. LPG Propane-Boiler (Central Heating System) A7

The Heat Loss Calculation Sheet obtained by using MS Excel is given in Table 1. Here, the heat loss of each independent area inside the apartment was calculated separately. Thermal transmittance value of each building component (walls, windows, ceiling, flooring etc.) has been determined. Average outside temperature and heating-cooling day values are obtained from the database of the General Directorate of Meteorology. Room dimensions are obtained by using AutoCAD. The remaining values are obtained from the standard TS-825: Heat Insulation Rules in Buildings.

Table 1. Heat loss account for independent space

HEAT LOSS ACCOUNT SCHEDULE Northwest Ground Floor Flat													
		Surface Calculation					Heat Loss Account						
Mark	**Direction**	Length	Ht &Wd	Surface	Number of area	Disregarded	Considered	K	Temperature Difference (Dt)	K x Dt	Heat Loss	Z:Total Addition	Qh:Heat Req.
		m	**m**	**m²**	**Ad**	**m²**	**m²**	**Watt/ m²K**	**K**	**Watt/ m²**	**Watt**	**1+%**	**Watt**
		Z01		Main Bedroom			20	oC					
EW1	NW	3,6	3,0	10,8	1		10,8	0,51	20	10,1	109,3		
DGW1	NW	1,6	2,0	3,2	1		3,2	2,80	20	56,0	179,2		
EW1	NW	3,5	3,0	10,5	1	3,2	7,3	0,51	20	10,1	73,9		
DGW1	NW	0,7	1,7	1,2	1		1,2	2,80	20	56,0	66,6		
EW1	NW	1,0	3,0	3,0	1	1,2	1,8	0,51	20	10,1	18,3		
RO2				15,8	1		15,8	2,10	0	0,0	0,0		
FL2				15,8	1		15,8	2,10	10	21,0	31,9		
											779,2	1,12	873
	Qe =	2	x	12,0	x	0,90	x	0,97	x	23	x	1,2	+ 578
													1.451

Radiator lengths are determined for each climate zone and for two different heating system conditions, based on the heat loss values of the building, and then installation costs are calculated. Installation costs are given in Table 2. While calculating the installation costs, "2019 Construction and Installation Unit Price Book" of the Ministry of Environment and Urbanization is used. The installation costs provided in Table 2 are for one climate zone. In parallel with the increase in heat demand, the installation cost of other climatic zones would be higher.

Table 2. Installation cost (for climate zone 1)

Fuel-System Combination	Installation Cost
Natural Gas-Combi Boiler	48.713,31 USD
Natural Gas-Boiler	30.865,84 USD
Fuel Oil-Boiler	28.899,34 USD
Lignite +18 mm. Boiler	29.045,94 USD
Lignite +20 mm. Boiler	29.045,94 USD
Imported Coal-Boiler	29.045,94 USD
LPG-Propane-Boiler	31.615,84 USD

Depending on the radiator lengths, thermal loads that the system will use are calculated. The amount of annually consumed fuel is obtained depending on the fuel lower heat value and system efficiency. In order to calculate the annual amount of fuel, it is necessary to know unit cost of the fuel. In this calculation, needed data for the fuel are taken from the 277th issue of Tesisat Magazine published at 17.01.2019. The unit costs have also been checked from the websites of the specified energy companies. Annual fuel consumption is calculated by using Equation 1.

$$T_{YYT} = \frac{(Q_h \times z \times Z)}{(2 \times H_u \times n_k)} \ USD \quad (1)$$

Q_h = Heat requirement in one hour (kcal/hour)
z = Daily working time (hour)
Z = Annual working time according to climatic conditions (day)
H_u = Lower heat value of fuel (kcal/m3 or kg)
n_k = Heat generator efficiency

The annual fuel cost of the alternatives for the 1st Region obtained from Equation 1 are given in Table 3.

Table 3. Annual fuel consumption costs (for climate zone 1)

Fuel-System Combination	Annual Fuel Consumption Costs
Natural Gas-Combi Boiler	15.654,96 USD
Natural Gas-Boiler	9.275,04 USD
Fuel Oil-Boiler	30.453,04 USD
Lignite +18 mm. Boiler	15.576,77 USD
Lignite +20 mm. Boiler	16.036,89 USD
Imported Coal-Boiler	21.517,17 USD
LPG-Propane-Boiler	41.890,01 USD

Using the annual fuel consumption, TS EN ISO 14064-1,2,3 Greenhouse Gas Calculation Standards [21] and the IPCC (Intergovernmental Panel on Climate Change) 5. Evaluation Report [22], the greenhouse gas emission amount is calculated by using Equation 2 for each alternative.

$$E = B \times H_u \times e_f \times 4186{,}6 \times 10^{-12} \times 10^{-3} \quad (2)$$

E = Greenhouse gas emission amount (ton*emission)
B = Annual fuel amount (m3 or kg/year)
H_u = Fuel's lower thermal value (kcal\ m3 or kg)
e_f = Emission factor (kg\Tj)

Emission factors and emission conversion coefficients are taken with respect to the assumptions in the 5th Evaluation Report and these emission values are given in Table 4 as CO_2.

Table 4. Annual greenhouse gas emission amount (for climate zone 1)

Fuel-System Combination	Annual Greenhouse Gas Emission Amount
Natural Gas-Combi Boiler	133,104 ton CO2
Natural Gas-Boiler	78,859 ton CO2
Fuel Oil-Boiler	145,913 ton CO2
Lignite +18 mm. Boiler	253,318 ton CO2
Lignite +20 mm. Boiler	271,931 ton CO2
Imported Coal-Boiler	238,552 ton CO2
LPG-Propane-Boiler	89,506 ton CO2

Maintenance costs for the central system using different fuels and for the individual system with natural gas are determined by the offerings received from the companies serving in this field available in the market. The recieved offerings are collected under the chamber of the market price research report and the average values of these offeringsare taken. Average maintenance costs are given in Table 5. To compare, individual system maintenance has been taken as total for all apartments.

Table 5. Annual maintenance costs (for climate zone 1)

Fuel-System Combination	Annual Maintenance Costs
Natural Gas-Combi Boiler	1.200 USD
Natural Gas-Boiler	500 USD
Fuel Oil-Boiler	750 USD
Lignite +18 mm. Boiler	625 USD
Lignite +20 mm. Boiler	625 USD
Imported Coal-Boiler	625 USD
LPG-Propane-Boiler	675 USD

As the simpleness of operation and fuel storage status are not quantitative observations, it is not be possible to make a comparison as in the first four criteria. For these criteria, Analytical Hierarchy Process, which is one of the multi-criteria decision making methods, is used by assigning a value for the evaluation.

4. Evaluation

Up to this part of the study, the first four criteria which are fuel cost, greenhouse gas emission, installation cost and maintenance cost are calculated. For the other two criteria, alternatives would be listed. While making this ranking and then classifying the criteria among themselves, the Analytical Hierarchy Process, which is a multi-criteria decision making method, is used. In the first part of evaluation, criteria weights are determined by Analytical Hierarchy Process. Criterion weights play an important role in decision making sincethe result will change if weights change. Therefore, in order to make a proper selection, binary comparisons of the Analytical Hierarchy Process are presented as a questionnaire and the geometric mean of the results of this questionnaire is calculated.

4.1. Criterion weighting with analytical hierarchy process

Analytical Hierarchy Process is a multi-criteria decision making method developed by Thomas L. Saaty in the 1970s and nowadays it is widely used for the solution of complex decision problems [23].

The hierarchical structure of the Analytical Hierarchy Process is shown in Figure 2.

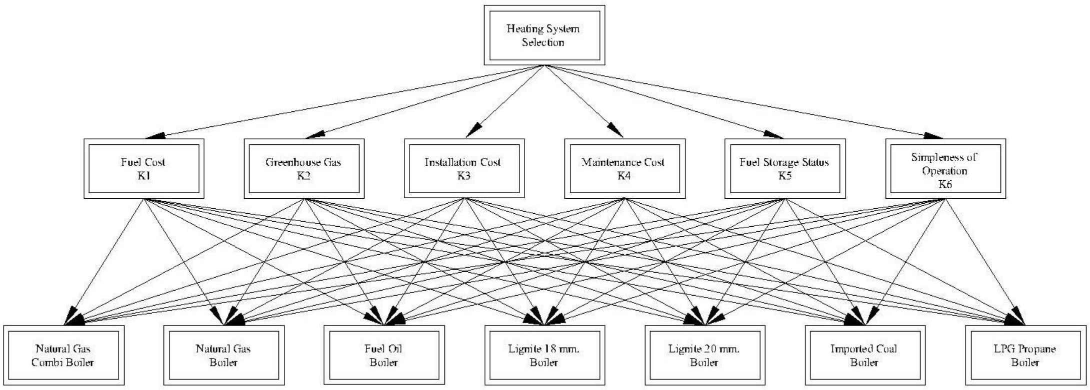


Figure 2. The Relationship between criteria and alternatives according to AHP

In the Analytical Hierarchy Process, the decisions of the decision maker are taken as basis for determining the relative significance of all the criteria. To make this assessment, Saaty questionnaire is created as having 1-9 scale. The relationship of each criterion with another criterion is scored in this questionnaire with respect to the degree of importance. Questionnaire results are examined in matrices to determine the order of importance of the criteria [24].

The definition of the scale 1-9 used in the Analytical Hierarchy Process is given in Table 6. While this evaluation scale is used in binary comparisons, it gives 1/9 as the lowest value and 9 as the highest value [25]. The questionnaire which is carried out for binary ratings based on the scale specified in this study is given in Table 7.

Table 6. Scale of relative importance

Importance Level	Definition	Explain
1	Equal Importance	Two activities contribute equally to the objective
3	Moderate Importance	Experience and judgment slightly favor one activity over another
5	Strong Importance	Experience and judgment strongly favor one activity over another
7	Very Strong Importance	An activity is favored very strongly over another
9	Extreme Importance	The evidence favoring one activity over another is one of the highest possible order
2,4,6,8	Intermediate Values	Used to represent compromise between the priorities listed above

After the binary ratings of the criteria are accomplished, the matrix operations of AHS are performed and the criteria weights are found. The binary ratings of the criteria are used for the geometric mean of these values which are obtained as a result of the surveys conducted by mechanical engineers working in this field. AHS procedures are finally completed and the criteria weights obtained within acceptable limits as a result of consistency analysis are given in Table 8.

Similar AHP operations are repeated for the purpose of assigning a value for simpleness of operation and fuel storage status criteria, where quantitative calculations are not possible. The numerical values obtained for these criteria are given in Table 9.

Table 7. Binary rating survey of criteria on Saaty Scale

Criteria	Saaty Scale																	Criteria
Fuel Cost	9	8	7	6	**5**	4	3	2	1	2	3	4	5	6	7	8	9	Installation Cost
Fuel Cost	9	8	**7**	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Fuel Storage Status
Fuel Cost	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Amount of Emission
Fuel Cost	9	8	7	**6**	5	4	3	2	1	2	3	4	5	6	7	8	9	Simpleness of Operation
Fuel Cost	9	8	7	6	5	4	**3**	2	1	2	3	4	5	6	7	8	9	Maintenance Cost
Installation Cost	9	8	7	6	5	**4**	3	2	1	2	3	4	5	6	7	8	9	Fuel Storage Status
Installation Cost	9	8	7	6	5	4	3	2	1	**2**	3	4	5	6	7	8	9	Amount of Emission
Installation Cost	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Simpleness of Operation
Installation Cost	9	8	7	6	5	4	3	2	1	**2**	3	4	5	6	7	8	9	Maintenance Cost
Fuel Storage Status	9	8	7	6	5	4	3	2	1	2	3	4	**5**	6	7	8	9	Amount of Emission
Fuel Storage Status	9	8	7	6	5	4	3	2	1	2	3	**4**	5	6	7	8	9	Simpleness of Operation
Fuel Storage Status	9	8	7	6	5	4	3	2	1	**2**	3	4	5	6	7	8	9	Maintenance Cost
Amount of Emission	9	8	7	6	**5**	4	3	2	1	2	3	4	5	6	7	8	9	Simpleness of Operation
Amount of Emission	9	8	7	6	5	**4**	3	2	1	2	3	4	5	6	7	8	9	Maintenance Cost
Simpleness of Operation	9	8	7	6	5	4	**3**	2	1	2	3	4	5	6	7	8	9	Maintenance Cost

Table 8. Criterion weights resulting from AHP

Fuel-System Combination	Criterion Weights Resulting from AHP
Fuel Cost	35,145%
Installation Cost	10,117%
Fuel Storage Status	4,140%
Amount of Emission	30,011%
Simpleness of Operation	8,036%
Maintenance Cost	12,552%

Table 9. Values of simpleness of operation and fuel storage status criteria achieved with AHP

Simpleness of Operation			Fuel Storage Status		
Alternatives	Percentage	Preference Rate	Alternatives	Percentage	Preference Rate
A1	35,431 %	7,43	A1	38,879 %	9,65
A2	21,957 %	4,60	A2	20,168 %	5,01
A3	10,447 %	2,19	A3	4,028 %	1,00
A4	4,772 %	1,00	A4	6,555 %	1,63
A5	4,772 %	1,00	A5	6,555 %	1,63
A6	4,772 %	1,00	A6	6,555 %	1,63
A7	17,849 %	3,74	A7	17,260 %	4,29

In the study so far, the numerical values of the alternatives under the criteria and the hierarchical structure (weights) of the criteria among themselves are determined. Under the criteria discussed at the beginning of this study, TOPSIS and VIKOR methods are used to find the optimum result by choosing from the alternatives.

4.2. Making selection with TOPSIS method

The TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method is one of the multi-criteria decision making methods and developed by Hwang and Yoon in 1981 [26]. It is established based on the assumption that the alternative solution point is the shortest distance to the positive-ideal solution and the farthest distance to the negative-ideal solution. TOPSIS method does not make a qualitative conversion, it can be applied directly on the data [27].

For example, if the goal is making profit, the proximity to the ideal solution means maximizing the profit, and the distance to the negative ideal solution means minimizing the cost. If the ideal solution is not implemented or achieved, the point closest to the ideal solution must be selected [28].

TOPSIS method also has implementation steps and matrix solutions similar to AHP. In the flow chart given in Figure 3, the steps of the TOPSIS method are given in order. It is clearly seen from the flow chart where AHP is involved in the transaction.

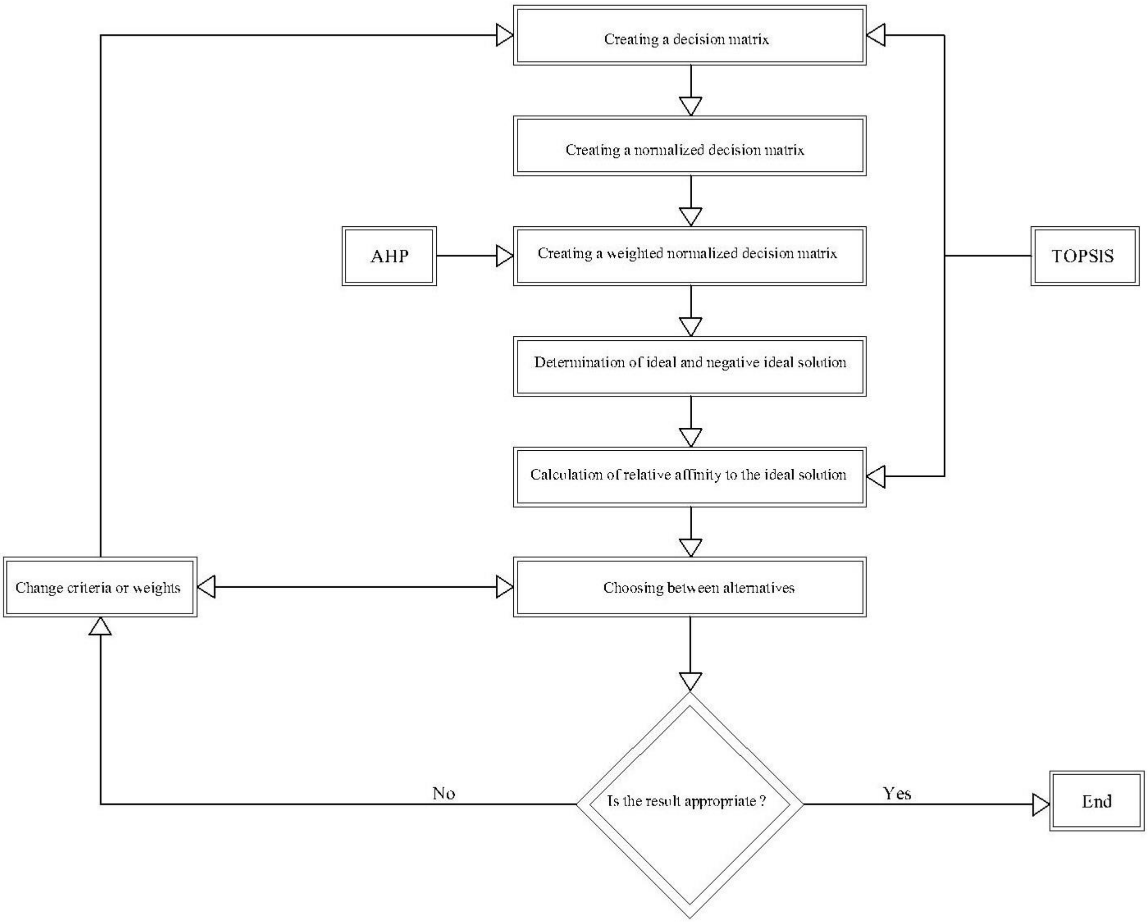


Figure 3. TOPSIS flow chart

When the related matrix operations are solved by following the flow chart above, the results in Table 10 is obtained by using the TOPSIS method. TOPSIS method determines the best result (ideal) and the worst result (non-ideal) by getting the best and the worst results under each criterion among the alternatives. Then, a result has been accomplished by looking at the proximity to the best result and distance to the worst result, that are obtained by using TOPSIS. The values in Table 10 are the ideal proximity values of the selection.

As a result of the selection with the TOPSIS method, the ideal solution, which is the closest result to the value of "1", is the Natural Gas-Boiler system with approximately 88%. The second result is the Natural Gas-Combi, or individual system, with about 75%. This calculation is repeated for all climatic zones where the hypothetical building is located.

4.3. Making selection with VIKOR method

The VIKOR method, designed by Serafim Opricovic and Gwo-Hshiung Tzeng (2004), is one of the multi-criteria decision analysis methods [29]. It is designed to offer a compromised solution set, that targets maximum group benefit and minimum individual regret in decision problems with opposite criteria. The VIKOR (The Vise Kriterjumska Optimizacija I Kompromisno Resenje) method has been developed for the optimization of complex systems [30].

Table 10. TOPSIS ideal solution proximity value

Fuel-System Combination	Ci* (Ideal Solution Proximity Value)	Ranking
Natural Gas-Combi Boiler	0,749662	2
Natural Gas-Boiler	0,876127	1
Fuel Oil-Boiler	0,448229	6
Lignite +18 mm. Boiler	0,512380	3
Lignite +20 mm. Boiler	0,487274	4
Imported Coal-Boiler	0,451017	5
LPG-Propane-Boiler	0,420294	7

Like the TOPSIS method, the VIKOR method requests weight vectors from the decision maker. Therefore, the weight vectors wearere determined by the Analytical Hierarchy Process at the beginning of this study. The operating logic of AHP and VIKOR method working together is shown in Figure 4 [31]. The operating logic of AHP and TOPSIS method working together is the same.

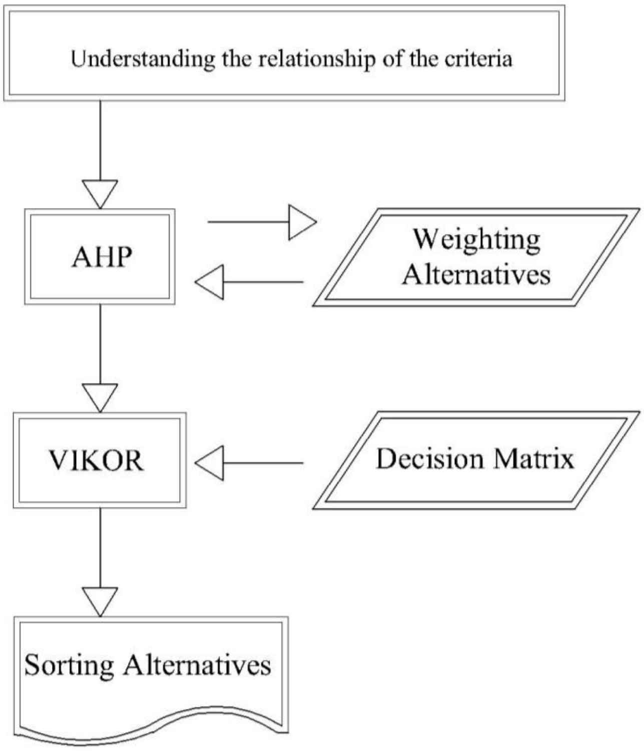


Figure 4. VIKOR flow chart

The aim ofusing VIKOR method is to reach a compromised solution. It targets the minimum individual regret based on the maximum group benefit. The compromise solution is the closest solution to the ideal, and compromise is to reach an agreement on common acceptance. According to the VIKOR method, the closest option to the ideal solution is the first choice. The values in Table 11 are obtained by repeating the relevant matrix operations by using VIKOR method. Maximum group benefit is calculated according to veto, consensus and majority status; and alternatives are ranked. The ranking is given in Table 12. The control of the conditions (advantage and acceptable stability) of the VIKOR method and its results are shown in Table 13.

According to veto, consensus and majority conditions, the best alternative is the Natural Gas-Boiler central system, while the second best alternative is the Natural Gas-Combi individual system. As a result of VIKOR Analysis for the Problem of Selecting the Best Heating System, it is shown that the Natural Gas-Boiler system is the most suitable one for the conditions of q = {0,00; 0,25; 0,50; 0,75; 1,00}, since the acceptable advantages and stability conditions are provided at the same time.

Table 11. Qi Values calculated by VIKOR Method

q:{0,00;0,25;0,50;0,75;1,00} Parameters q>0,50 "Majority" q=0,50 "Consensus" q<0,50 "Veto"					
0,00	**0,25**	**0,50**	**0,75**	**1,00**	
Qi (q=0,00)	**Qi (q=0,25)**	**Qi (q=0,50)**	**Qi (q=0,75)**	**Qi (q=1,00)**	**Fuel-System Combination**
0,285	0,386	0,486	0,586	0,687	Natural Gas-Combi Boiler
0,000	0,000	0,000	0,000	0,000	Natural Gas-Boiler
0,610	0,689	0,767	0,846	0,925	Fuel Oil-Boiler
0,746	0,787	0,828	0,868	0,909	Lignite +18 mm. Boiler
0,838	0,874	0,911	0,948	0,984	Lignite +20 mm. Boiler
0,673	0,755	0,837	0,918	1,000	Imported Coal-Boiler
1,000	0,977	0,955	0,932	0,910	LPG-Propane-Boiler

Table 12. Sorting alternatives with VIKOR Method

Parameters					
Qi (q=0,00)	**Qi (q=0,25)**	**Qi (q=0,50)**	**Qi (q=0,75)**	**Qi (q=1,00)**	**Fuel-System Combination**
2	2	2	2	2	Natural Gas-Combi Boiler
1	1	1	1	1	Natural Gas-Boiler
3	3	3	3	5	Fuel Oil-Boiler
5	5	4	4	3	Lignite +18 mm. Boiler
6	6	6	7	6	Lignite +20 mm. Boiler
4	4	5	5	7	Imported Coal-Boiler
7	7	7	6	4	LPG-Propane-Boiler

Table 13. Control of the conditions

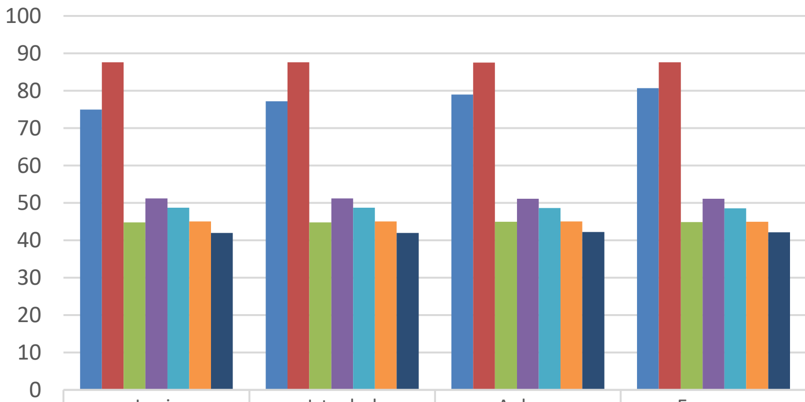
Parameters	**0,00**	**0,25**	**0,50**	**0,75**	**1,00**
Q(A2)	0,285	0,386	0,486	0,586	0,687
Q(A1)	0,000	0,000	0,000	0,000	0,000
Q(A2)-Q(A1)	0,285	0,386	0,486	0,586	0,687
DQ	0,167	0,167	0,167	0,167	0,167
Condition 1	Correct	Correct	Correct	Correct	Correct
Condition 2	Correct	Correct	Correct	Correct	Correct

5. Results and Discussion

The structure of Turkey are generally composed of multiple residential structures or in other words, apartments. From this point of view, an insulated building manufactured in accordance with general construction techniques in Turkey is considered. This study is carried out on the assumption that this building is placed in various cities selected from 4 different climate zones, taking place in the scope of TS 825. Structural and thermal load analysis are performed on the building and its parts by using MS Excel. The most commonly used two heating systems, individual and central heating systems, are tackled for total of 7 alternatives including individual system having single fuel and central system having 6 different fuels. The main reason why all of the alternatives are fossil fuel is that they are used with overwhelming superiority in space heating. The aim of this study is to select the best option from these fuels and heating systems, which which are not likely to be abandoned in the near future. Therefore, energy efficiency which is the most important point for reducing the fossil-related climatic damages is emphasized.

The performance of the building is tried to evaluated in terms of these alternatives for different climatic regions. Firstly, under what criteria it should be evaluated is considered; and then, the most sought-after features in heating systems are examined. The six most important criteria are identified while choosing a heating system. Four of these criteria are based on numerical data and two of them on experience. The mentioned criteria are fuel cost, greenhouse gas emission amount, installation cost, maintenance cost, simpleness of operation and fuel storage status. Numerical data are used at decision making phase. Relative assessment based on experience has been a different decision mechanism. While weighting these determined criteria, Fuel Cost and Greenhouse Gas Emission are wanted to be prioritized.

The results obtained by using AHP + TOPSIS are given in Figure 5 in visual and detailed form. When these data are analyzed, it is the Natural Gas-Boiler system that achieves the best results in 86-88% band among all regions. While the second best alternative, the Natural Gas-Individual system, has 75% in the province of Izmir in the 1st Climate Region, this rate reaches 81% when it comes to Erzurum, located in the 4th Climate Region. Therefore, it is concluded that as the outdoor temperature and heating time increase, the difference between the two best alternatives decreases. There is no such increase between in other alternatives. After the natural gas fired alternatives, there are coal fired alternatives in the ranking. The success rate of Soma Lignite alternatives, which gives almost the same results in all 4 Climate Zones, is around 50%. The main reason why lignite coal comes after natural gas within alternatives is the effect of the fuel cost criterion. Coal fuel has given the worst results among alternative fuels in greenhouse gas emission criteria, although its performance in fuel cost is good. For this reason, the success rate remained around 50%. When the lignite coal systems, import coal system and fuel-oil system, which have almost the same installation cost, are compared and it is seen that, imported coal comes after lignite fuel system, and fuel oil comes after imported coal. By using TOPSIS, imported coal and fuel oil systems, whose success performances are very close to each other, are examined. It is seen that the imported coal system has better results in fuel cost comparing to the fuel-oil system in greenhouse gas emission. LPG-Propane central system has the worst score among the alternatives. The main reason is that although it gives the second best result in greenhouse gas emission, the fuel cost is very high.



	Izmir	Istanbul	Ankara	Erzurum
Natural Gas-Combi Boiler	74,96615627	77,23887298	79,01353492	80,7394648
Natural Gas-Boiler	87,61268353	87,67595604	87,57534913	87,62349672
Fuel Oil Boiler	44,82292092	44,78254092	44,99372925	44,87762545
Coal (+18 mm. Soma Lignite) Boiler	51,23804251	51,25268616	51,15460822	51,13100663
Coal (+20 mm. Soma Lignite) Boiler	48,72743884	48,74167393	48,62677616	48,60218189
Coal (Import Siberia) Boiler	45,10172305	45,10218827	45,04485206	44,98364155
LPG Propane-Boiler	42,02937695	41,97417892	42,25993817	42,15466097

Figure 5. Status of alternatives across climate zones

Ranking of the criteria is obtained in the evaluation with AHP + VIKOR method, but no data can be obtained to determine how far they achieved the desired perfect result. VIKOR method is focused on the exact solution more than sequencing. It aims to select alternatives at an acceptable level in terms of the given criteria. According to VIKOR, there is a clear selection or a cluster of possible choices. VIKOR method gives exactly the same results with TOPSIS.

For this reason, the solution desired to be found in this study is obtained clearly. In the evaluation performed with two different multi-criteria decision making mechanisms, Natural Gas fueled central heating system provided the best result under the specified criteria for all climatic regions.

Another point to be evaluated in this study is to test the same fuel type for each province in different systems. In this way, the mathematical infrastructure of the importance of the energy economy can be clearly seen. For future directions in energy investment decisions, especially for countries with serious energy importers like Turkey, the term of "Energy Efficiency" should also considered as a source of energy at this present time. Energy efficiency has already taken a part among the energy sources as "Sixth Fuel" after coal, oil, natural gas, nuclear energy and renewable energy [32]. When this study is examined in terms of energy efficiency, the fuel difference between the systems of individual or central system, that have been designed fort he same building as heating systems, within a specified climate zone, is 40.75% for Izmir, 37.47% for Istanbul, 34.78% for Ankara and 32.15% for Erzurum. Turkey, where the majority of the population lives at rivage and which is highly dependent on imported energy, can save large amount of energy with the efficient use of heating energy. The profit rate that can be obtained in the central system is given in Figure 6 for Fuel Cost. While analyzing these data, it should not be forgotten that Erzurum is located in the 4th Climate Region; therefore, it consumes longer heating time and consequently more energy consumption. Thus, although profitability percentage tends to decrease towards Erzurum, savings would be higher on a building basis if consumption figures are taken into consideration. Population ratio of the provinces has been ignored since this study is conducted for a specific building. It is clear that the highest energy saving would belong to Istanbul if population raito of the provinces has been considered.

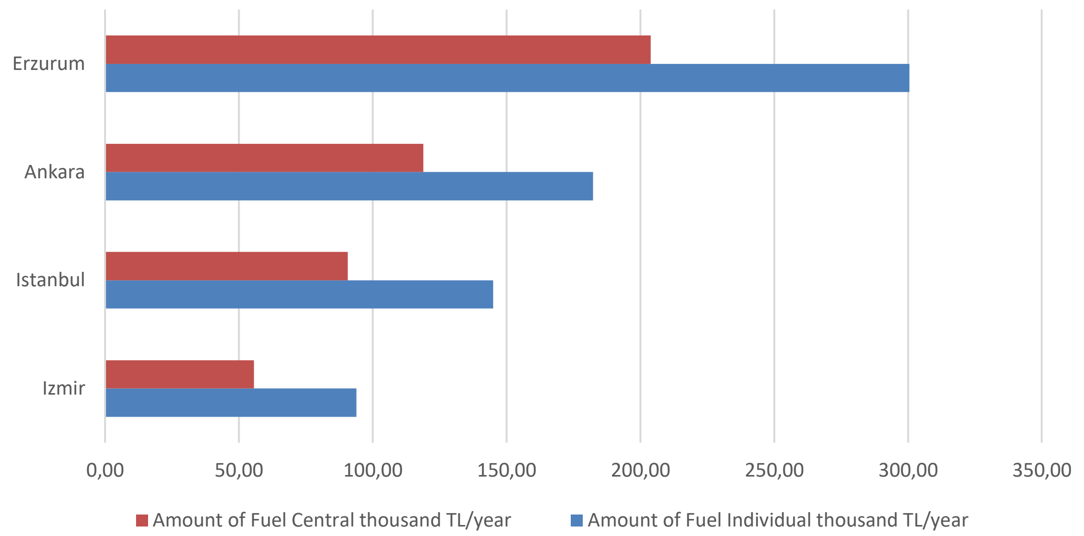


Figure 6. Comparison of fuel costs of the same fuel and different systems

People who live in Turkey, do not prefer warm with the central heating system. Within the scope of the Energy Efficiency Law (ENVER) and Regulation on Increasing Efficiency in the Use of Energy Resources and Energy Released, although it is obligatory to install suitable heating systems for energy efficiency in buildings that are built over a certain square meter in space heating, people still continue to return to the individual system by taking advantage of legal gaps [33]. The main reason is that sufficient heat value in the environment is a relative concept. In addition, in the buildings heated by the central heating system, the sensed temperature changes according to the location of the apartments. Although the direction coefficients are taken into account in heat calculations, the effect of the sun is undeniable. Even if the ambient temperature in the residences is equal to the temperature determined in the project, users consider the ambient temperature is insufficient [7]. For example, the apartment which is located the upper floor of the building on the north side, to the system is operated more to reach the specified temperature, whilethere is more heat than desired in the apartments on the lower floors. This is a problem among the hostssince fair heating cannot be provided in exchange for the price they pay. For this reason, it is required to raise the awareness of the public on the heat share meter system, which providesto pay as much as the amount of energy consumed.

This study can be expanded for different criteria or varying alternatives. The fossil-based systems used in this study can be combined with renewable energy sources whoseuse is increasing day by day. In this case, different criteria such as energy continuity, establishment, use and control of system automation should be taken into consideration. From another point of view, how much energy efficiency can be achieved by using passive heating techniques in architecture and its effects can be studied. Lignite coal-based alternatives will be on higher position if the study is carried out with respect to cyclical economy and consequently if a criterion that will prioritize the use of domestic fuel is added. These possibilities and possible scenarios can be further illustrated. The main objective is to reduce the damage to the environment with less consumption by establishing an energy efficient system. This study has also been completed for this purpose and a selection methodology has been developed for building heating between fossil-based systems.

Conflict of Interest Statement

The authors declare that there is no conflict of interest.

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