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RESEARCH ARTICLE

A hybrid QFD-AHP methodology and an application for heating systems in Turkey

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ABSTRACT

Selection of the heating system is based on many characteristics from the customer side. Operating cost, comfort, ease of use and aesthetic of the systems are some of the most important ones of these characteristics. In this article, data is collected primarily for the implementation of quality house. With these data, customer requirements are listed and defined in terms of degree of importance from the customer side. Then, the relationship between customer requirements and technical requirements are described. Also, column weights are calculated according to the defined relations. Finally, the results obtained using a quality house is integrated with Analytic Hierarchy Process (AHP) methodology for system selection. Then results are interpreted. The main contribution of this paper is to determine the best heating system selection using the relationship between customer and technical requirements. To the authors' knowledge, this will be the first study which uses the integrated QFD-AHP method for heating system selection.

1. Introduction and literature review

The residence is a spatiality that has economic value, changing value, aesthetical value and usage value. The residence is a building or a part of building which meets the necessities of people which provides a group of people to live separately from the others and which has a unique door by opening towards directly to the street.

During the all choices of MCDM (Multiple Criteria Decision Making) which aim to assist the decision maker in selection the best is implemented with the help of such methods as ELECTRE, TOPSIS, AHP, etc [1]. The Analytic Hierarchy Process is a methodology which is based on hierarchical structure of criteria, measurement and synthesis. AHP aims to help decision maker to get over the difficulties [2, 3]. Contrarily to other methods, AHP, given a number of functions, allows to specify the most desirable and objective value for each function. This occurs within a matrix of assessment in which the functions appear on both axes. The Quality Function Deployment (QFD)-AHP is a very flexible method, and allows analyzing customer's demands in an effective and objective manner. In particular, it permits to identify the customer's proper needs and to focus on the technical activity about output [4].

In the literature, based on the Analytic Hierarchy Process (AHP), the solar water heating system was the most inexpensive type heater in domestic use [5]. In conclusion, it was found that the solar water heating system was the most desirable system to be used in Jordan.

Nieminen and Huovila [6] described experiences of applying QFD in the decision making process in building design using the IEA (International Energy Agency) task with 23 criteria. Three case studies were shortly presented. The study [7] specified the fundamental requirements for a prioritization process. Where prioritization should take place during the requirements phase, and who should be involved in the prioritization process were studied. Current techniques such as AHP and QFD were analyzed to how well they satisfy the fundamental needs of a successful prioritization process. A framework was described that incorporates the many aspects of prioritizing requirements.

The thesis of Alanne [8] i) identified the need of decision support in the commercialization of

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sustainable energy technologies in buildings, ii) characterized decision-making problems related to the above context, iii) developed and implemented a methodology to assess energy technologies for buildings, and iv) presented two fields of application where the above assessment is essential. Moreover, a multi-criteria portfolio model was applied to determine the most preferred retrofit measures in an apartment building. In their paper, Alanne et al. [9] considered the selection of a residential energy supply system as a multi-criteria decision-making (AHP) problem, which involved both financial and environmental issues. On the other hand, as an update of Huang et al.'s article, the study of Zhou et al. [10] gave the developments of DA (Decision Analysis) in E&E (Energy and Environmental modeling) in recent years. That survey showed the increased popularity of MCDM methods. Besides, the working paper of Nebel et al. [11] was an interim report from the Systems Research Work Plan - "Criteria Development and Embedding Systems". Two systems were selected from a prioritized list of residential building systems obtained through a series of workshops and project team discussion meetings by AHP method. The aim of the work of De Felice and Petrillo [4] was to propose a new methodological approach about defining customer's specifications through the instrument of an integrated QFD-AHD model. AHP was well designed for that because of its mathematically and rigorous process for prioritization and decision making.

With this study, the hopes of people from heating systems which are used in the houses and which will be used at the future and the differences between these heating systems are emphasized. Customer demands are emphasized with the Quality Function Deployment (QFD) application and the technical requirements are listed and the comparison are made. And the technical necessaries are listed. AHP application is made by taking the results from Quality house application for system choosing. The alternatives are radiator, fan-coil, air-condition and floor heating systems. When we investigate the researches about this topic, QFD-AHP, a study that comprises all these four heating systems was not encountered. The provided results can be a numerically guide for the CIBSE Best Practice guide.

In the sections that follow, we first present the heating systems in Section 2. We then define QFD and methodology in Section 3. A QFD development for heating systems is explained in Section 4. A description of AHP methodology is given in Section 5. In Section 6, heating system selection using Analytic Hierarchy Process (AHP) is given. Finally, Section 7 concludes the paper and points future work.

2. Heating systems and exports in Turkey

A heating system is a mechanism for maintaining temperatures at an acceptable level; by using thermal energy within a home, office, or other dwelling. While considering about efficient energy rating, some factors are taken into consideration, such as thermal irregularities in building envelope, energy efficiency of the boilers, the distribution system and the performance of the control system [12]. The floor heating system has constituted the rate of 50% of the heating system in the recent days at Europe. The rest of the rate has been including radiator, convector and the others.

Also, heating systems and equipments consist of burners, boilers, radiators, water heaters, dehumidifiers, electric and non-electric heaters, stoves and their equipments. In 2013, heating systems and equipments export of Turkey increased by 3,7% with respect to previous year and reached US$ 1,9 billion. According to data of 2013, in Turkey's heating systems and equipments export, Iraq, United Kingdom, Germany, Azerbaijan, and Turkmenistan are the top five countries (Figure 1) [13].

Rank	Country	2009	2010	2011	2012	2013	Change 12-13 %	2013 Share
1	Iraq	118.904	127.560	152.138	229.711	217.390	-5,36%	10,96%
2	United Kingdom	174.638	163.740	191.900	182.377	198.679	8,94%	10,01%
3	Germany	85.773	77.177	195.111	189.025	174.760	-7,55%	8,81%
4	Azerbaijan	49.441	52.466	86.700	98.154	140.604	43,25%	7,09%
5	Turkmenistan	76.206	84.619	106.752	90.061	102.686	14,02%	5,18%
6	Russian Federation	50.046	30.762	38.392	57.595	85.118	47,79%	4,29%
7	France	40.455	47.963	66.610	57.340	59.304	3,43%	2,99%
8	China	8.924	15.446	20.824	32.238	54.724	69,75%	2,76%
9	Romania	61.975	57.823	63.078	55.203	53.586	-2,93%	2,70%
10	Oman	2.345	2.025	2.785	37.892	51.618	36,22%	2,60%
11	Ukraine	39.638	42.701	56.690	54.892	49.215	-10,34%	2,48%
12	Italy	22.987	30.352	49.357	42.046	42.391	0,82%	2,14%
13	Saudi Arabia	35.379	31.501	18.148	39.132	41.202	5,29%	2,08%
14	Libya	62.073	53.256	12.574	31.393	35.157	11,99%	1,77%
15	Iran	12.273	29.246	51.366	49.975	34.660	-30,65%	1,75%
16	Spain	35.487	36.727	35.995	36.008	34.536	-4,09%	1,74%
17	Georgia	15.154	20.106	30.877	36.515	32.982	-9,68%	1,66%
18	Poland	21.935	23.322	32.019	26.967	30.373	12,63%	1,53%
19	Algeria	32.211	16.485	22.630	47.399	27.433	-42,12%	1,38%
20	Belgium	12.342	15.028	14.465	21.506	27.143	26,21%	1,37%
Others		**474.929**	**435.073**	**452.904**	**497.275**	**490.512**	**-1,36%**	**24,72%**
TOTAL		**1.433.138**	**1.393.378**	**1.701.345**	**1.912.700**	**1.984.063**	**3,73%**	**100,00%**

Figure 1. Turkey heating systems and equipments export by country (thousand $) [13].

2.1. Floor heating systems

Simulation model of floor heating system is mainly introduced as heat transfers in pipe to indoor and also this usage of it is approved as the basic shape for characterization and dimension. Different types of floor heating system have been investigated and at this point it is considered to being of finited element models with respect to thermal properties and dynamical behavior. The classification of the thermal output to indoor has been established with the purpose of being able to designed and dimensioned such as system in EN1264. Various kinds of control strategies are investigated not to loss indoor heat and consume the energy. Various floor covering materials have been found to impact temperatures, reaction time and energy consumption [14]. The heating floor elements such as, water, coils, electric cables are placed into concrete layer in the floor [15].

2.2. Radiator heating systems

As for radiator systems, the movement of the air heated by grazing the hot radiator surfaces towards the part of the room that is close to the ceiling and the presence of relatively cool air at the inferior half of the room which is the real usage capacity cannot be prevented. Because of this sufficiency of the heat diffusion at the horizontal and vertical sections in the room, the pleasant warmth on the floor surface and the thermal satisfaction of the person with the wall radiation effect in the floor heating, many practitioners confirm that the room temperatures anticipated in the planning of the floor heating need to be kept 1 – 2 ºC lower than the room temperatures given in the literature. Considering that a decrease of 1 ºC in the room temperature leads to a fuel economy of 7%, the superiority of the system on this matter can be emphasized.

In the current survey, a high powered density radiator using for the hydronic central heating applications has been developed for utilizing heat pipes. A heat pipe is hermetically sealed a light-water tube which exists inside the heat pipe shell as vapor and liquid at equilibrium [16]. In order to release hot weather from the distribution system into the building to save indoor energy and temperature, the heat emitters are used. Heat emitters which are commonly used are radiators, under-floor heating, fan-coil units (FCU) and air-handling units (AHU). This survey also showed that 95% of radiators were controlled by using TRVs (thermostatic radiator valves) and revealed that more than 65% of TRVs were performing very poorly [12].

2.3. Fan coil heating systems

First of all, fan coil system using is very useful and easy. Secondly, devices which could be hidden are comparatively aesthetic. Warming period is fastly reacting to the environment. Finally, system is relatively controllable.

2.4. Air-condition heating systems

Although the Turkish HVAC-R (heating, ventilating and air-conditioning & refrigeration) sector began to get organized in 1993, Turkey’s interest in the heating, ventilating, and air-conditioning sector dates back to the 1950’s. After that time, this industry has grown quickly both in terms of manufacturing and volume, expending its domestic and foreign markets. This growth has been expedited by a number of factors, including Turkey’s young population, the country’s steadily increasing GDP (gross domestic product), and the public’s growing demand for comfortable living standards [17].

The utilization of the system is very useful as fan coil heating systems. Also, system is fairly flexible due to the equipment could be camouflaged. The reaction of the system is very expeditious in terms of warm-up time. Besides, it can be simply controlled in terms of inspection. But, climate heating systems cannot be operating much more efficient in cold climate regions.

3. QFD and QFD methodology

Quality Function Deployment is a systematic approach to design based on a close awareness of customer desires, coupled with the integration of corporate functional groups. It consists in translating customer desires (for example, the ease of writing for a pen) into design characteristics (pen ink viscosity, pressure on ball-point) for each stage of the product development [18]. Figure 2 shows the quality house basic parts. Also, the main parts of a quality house matrix presented in Figure 3 is modeled.

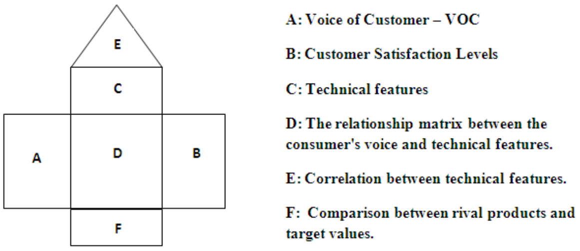


Figure 2. Quality house basic parts.

In this study, firstly the customer requirements were defined for quality house (QFD) application. Survey and double meetings were made when these requirements are defining. The quality house application was made with the data that was taken from surveys and AHP application in heating system selection was made in accordance with customer needs.

Beginning with the initial matrix, commonly referred as quality house (Figure 3), the QFD methodology focuses on the most important product or service attributes or qualities. These are composed of customer wants, and musts. Firstly, customer requests and technical requirements are determined. Then the relation between the customer request and technical requirements and the relation between the technical features are defined.

Evaluation of customers and technical evaluation according to competition are found and according to the firm goals technical importance values and normalized technical importance values are calculated as detailed in Section 4.

The methodology is summarized as shown in the Figure 4.

4. A QFD development for heating systems

The aim of this application is to see the applicability of QFD technique in the heating systems that based on customer expectations and customer satisfactions.

4.1. Forming the customer data part of the QFD matrix

4.1.1. Determining the customer demands

Expectations and demands from the heating systems and the selection criteria for the heating systems are asked to the customers and technical requirements are determined as shown in Table 1.

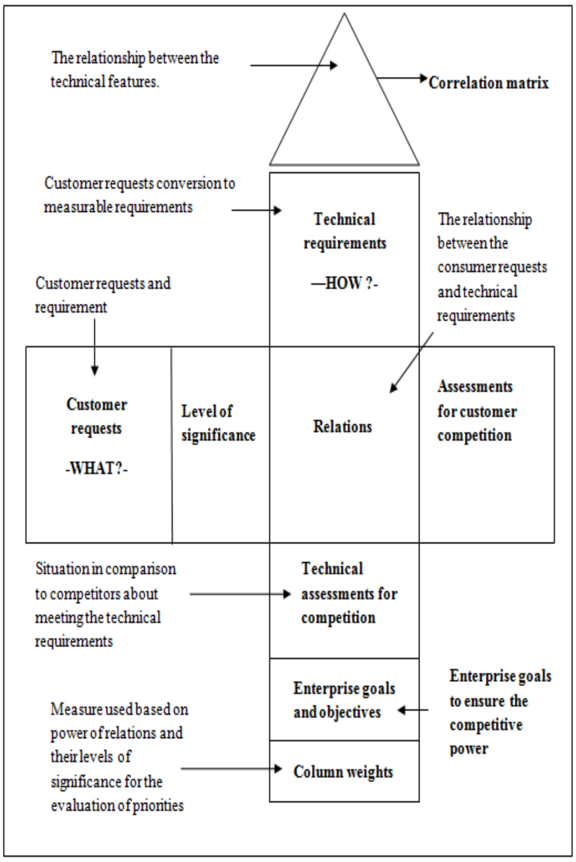


Figure 3. Quality house matrix basic parts.

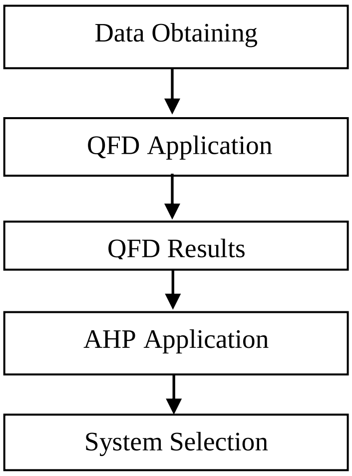


Figure 4. Methodology.

4.2. Arranging the relation between customer demands and the technical requirements

Customers' views are scaled with 1-9 scale that demonstrates 1-the least important, 9-the most important. Also firm experts are evaluated radiator system and floor heating systems with 1-5 scale that demonstrates 1-the worst, 5-the best as shown in Figure 5.

Table 1. Customer demands and the technical requirements for the heating systems.

Customer Demands	Technical Requirements
To be comfortable	Regular heat diffusion
To work with low operating costs	Heat insulation
To be aesthetic	Hidden devices and pipes
To be easy to use	Using thermostat
To response quickly	Ability to work in high-temperatures
To be responsive to the environment	Low CO_2 emission
Not to dust	Low temperature systems
To be compatible with the renewable energy sources	Ability to work with solar power
To save energy	High productive systems
To be easy to control	Using control equipment
To have smart appearance	Aesthetic devices
To be hide out	Hidden systems to the ceiling or to the ground
Ability to work with the outer air	Outer air temperature control
Ability to control each room detached	Thermostatic valves

4.3. Correlations and calculating the column weights

There can be positive or negative interactions between technical requirements that defined for covering the customer demands. Therefore "correlation matrix" is used for seeing these interactions.

In this matrix each cell represents the correlation between two different technical requirements and the positive relation can be shown with ✓ and the negative relation can be shown with X. The most important advantage of correlation matrix is being an indicator of negative relations. Each of the negative relation must be inspected while developing the product. Therefore the changes are determined that can be done for reducing the effect of any negative correlation. After determining the development direction the column weights are calculated (strong, middle, and low relations have 9, 3, 1 weights, respectively).

As an example, "to work with low operating costs" has 9 importance scales and has a strong relation with "heat insulation". Technical importance=Importance scale x Relation weight =9 x 9 = 81.

4.4. Analysis of the QFD matrix

As seen on Figure 6, the customer demands for heating systems are evaluated and the most important results of the house of quality for heating systems are; to be comfortable (8), to work with low operating costs (9), not to dust (8), to save energy (9), to have smart appearance (8), ability to control each room detached (8).

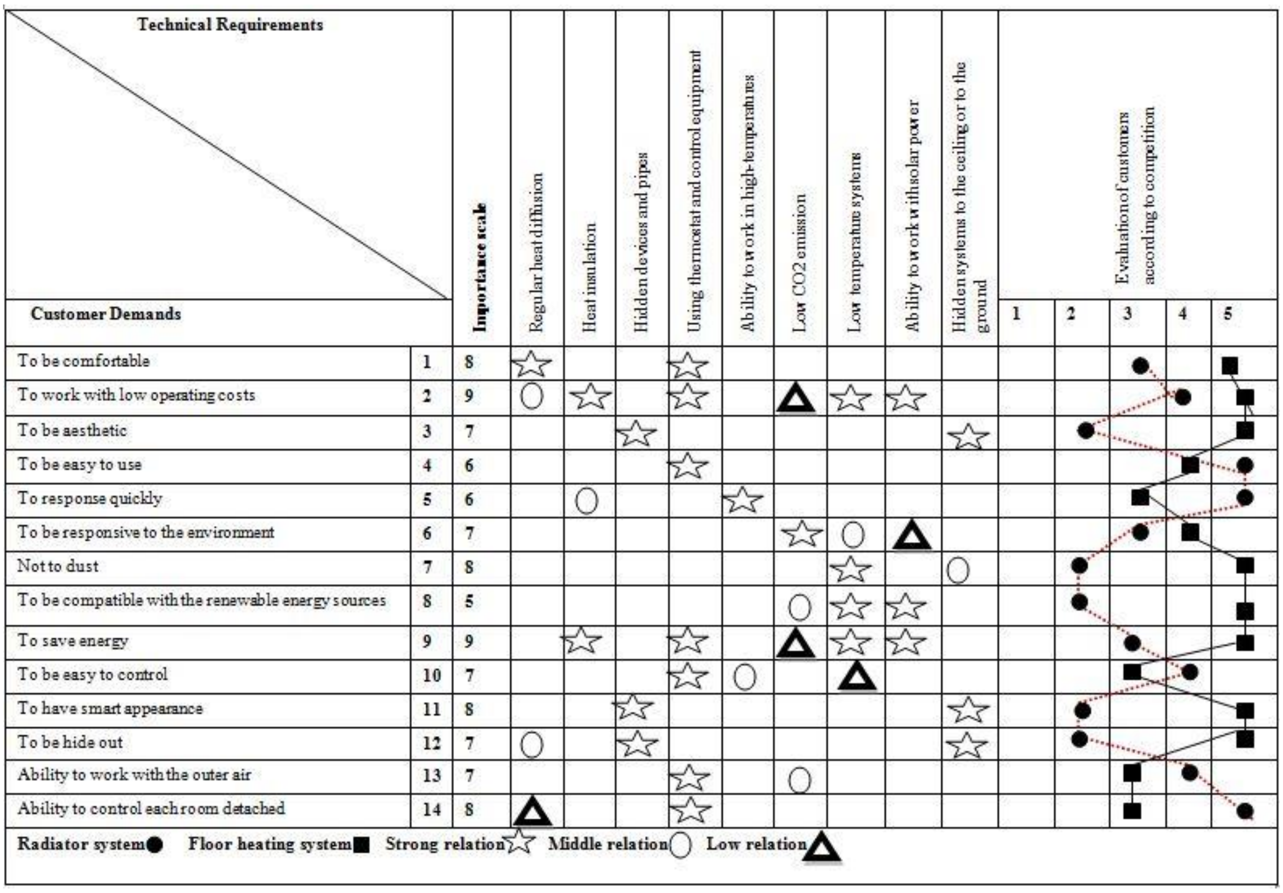
The analyzed firm in this study prefers mostly floor heating systems, therefore radiator systems are competitor for floor heating systems. But having regular heat diffusion, hidden devices and pipes and ability to work efficiently at low temperatures reinforce floor heating systems. Also ability to work efficiently at low temperatures causes to work with low operating costs, so one of the most important results for customer demands is satisfied.

From the technical importance point of view, the most important point is "using thermostat and control equipment". Therefore using these equipment causes to save energy, to be comfortable and ability to control the system according to the temperature of outer air.

As a development direction point of view, buildings that save more energy can be made with increasing the thickness of the insulation. Low operating costs can be obtained with increasing the number of thermostat and control equipment. For the purpose of reducing CO2 emission and being responsive to the environment, central boiler rooms must be enforced.

The analysis of the QFD matrix is concluded with the interpretation of the technical importance and normalized technical importance values. Technical requirements that have the maximum technical importance values are respectively;

- Using thermostat and control equipment
- Low temperature systems
- Hidden systems to the ceiling or to the ground
- Ability to work with solar power
- Hidden devices and pipes



Technical Requirements / Customer Demands		Importance scale	Regular heat diffusion	Heat insulation	Hidden devices and pipes	Using thermostat and control equipment	Ability to work in high-temperatures	Low CO2 emission	Low temperature systems	Ability to work with solar power	Hidden systems to the ceiling or to the ground	Evaluation of customers according to competition				
												1	2	3	4	5
To be comfortable	1	8	☆			☆								●		■
To work with low operating costs	2	9	○	☆		☆		△	☆	☆					●	■
To be aesthetic	3	7			☆						☆		●			■
To be easy to use	4	6				☆									■	●
To response quickly	5	6		○			☆							■		●
To be responsive to the environment	6	7						☆	○	△				●	■	
Not to dust	7	8							☆		○		●			■
To be compatible with the renewable energy sources	8	5						○	☆	☆			●			■
To save energy	9	9		☆		☆		△	☆	☆				●		■
To be easy to control	10	7				☆	○		△					■	●	
To have smart appearance	11	8			☆						☆		●			■
To be hide out	12	7	○		☆						☆		●			■
Ability to work with the outer air	13	7				☆		○						■	●	
Ability to control each room detached	14	8	△			☆								■		●

Radiator system ● **Floor heating system** ■ **Strong relation** ☆ **Middle relation** ○ **Low relation** △

Figure 5. The relation between customer demands and the technical requirements.

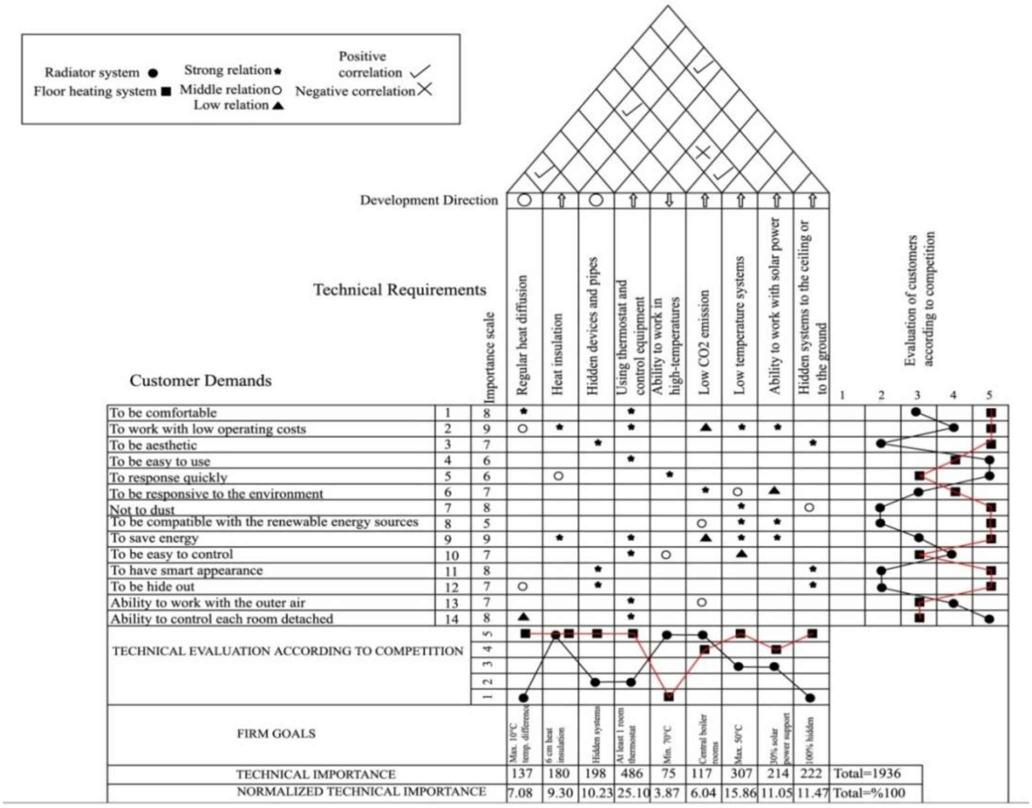


Figure 6. The house of quality for heating systems.

For the purpose of satisfying these technical requirements and customer demands, some heating systems alternatives will be evaluated and prioritized in the Section 6 using Analytic Hierarchy Process (AHP). Customer demands with high importance values will be the criteria for the heating system evaluation process. Therefore we will combine QFD with AHP.

5. Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a multi-criteria decision-making method that has been widely used since 1970s. It separates a problem into smaller pieces and examines the effect of these parts on each other. As a result of this process, the weight of parts and the importance order of parts are obtained. For this purpose, a benchmark scale was established that quantitatively assesses the effects of parts on each other. Parts of the problem are compared pair wise and effects of each part on the target are quantitatively obtained. The AHP method can be used in both social and physical areas to make measurement [19].

Steps of AHP is given below;

1. Identification of the problem and determination of the desired information,
2. Formation of the hierarchy of decision-making from top to bottom determination of the goal and criteria,
3. Obtaining pair wise comparison matrix,
4. Finding weights of criteria.

There is a need for a scale to make comparisons. This scale shows how important an element is compared to the other element. The scale used in AHP can be seen in Table 2 [20].

Table 2. AHP Scale.

Importance Values	Value Definitions	Explanation
1	Both factors are equally important	Both activities have an equal importance.
3	Factor 1 is slightly more important than Factor 2	Experience and judgment shows that Factor 1 is slightly more important than the other.
5	Factor 1 is more important than Factor 2	Experience and judgment shows that Factor 1 is more important than the other.
7	Factor 1 is strongly more important than Factor 2	Experience and judgment shows that Factor 1 is strongly more important than Factor 2.
9	Factor 1 has absolute superiority over Factor 2	Experience and judgment shows that Factor 1 is absolutely more important than the other.

The mathematical realization of AHP will be explained in the following steps [21].

1. First, the problem and elements (criteria) to be decided are defined. Using these elements, a comparison matrix is constructed. The comparison

matrix for "n" elements contains "nxn" elements and the values on the diagonal (where i = j) are 1.

$$K = \begin{bmatrix} k_{11} & k_{12} & \cdots & k_{1n} \\ k_{21} & k_{22} & \cdots & k_{2n} \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ k_{n1} & k_{n2} & \cdots & k_{nn} \end{bmatrix} \quad (1)$$

In the comparison matrix there is such relation, between the elements above the diagonal and the elements below the diagonal;

$$k_{ji} = \frac{1}{k_{ij}} \quad (2)$$

For example, if the third criterion more important than the second criterion, the value of element k_{23} is 5 and k_{32} element has a value of 1/5.

2. This matrix shows us the importance of each criterion, but does not allow us to see the weight of each criterion in total. We need to get the column vectors for this. Each element is divided by the sum of the values in its column, and if the value is substituted, n column vectors of n elements are obtained.

$$s_{ij} = \frac{k_{ij}}{\sum_{i=1}^{n} k_{ij}} \quad (3)$$

The above formula is used when the values of the column vector are calculated.

$$S_i = \begin{bmatrix} s_{11} \\ s_{21} \\ \cdot \\ \cdot \\ \cdot \\ s_{n1} \end{bmatrix} \quad (4)$$

3. To create column matrix, n column vectors are are formed in a matrix. This matrix is as follows

$$S = \begin{bmatrix} s_{11} & s_{12} & \cdots & s_{1n} \\ s_{21} & s_{22} & \cdots & s_{2n} \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ s_{n1} & s_{n2} & \cdots & s_{nn} \end{bmatrix} \quad (5)$$

4. Finally, using the S matrix, we need to obtain the weight vector to obtain the percentage of the elements. This is obtained by taking the arithmetic mean of the elements in the rows of the column matrix.

$$A_i = \frac{\sum_{j=1}^{n} s_{ij}}{n} \quad (6)$$

The sum of the elements of the weight vector is 1. The weight vector is as follows;

$$A = \begin{bmatrix} a_1 \\ a_2 \\ \cdot \\ \cdot \\ \cdot \\ a_n \end{bmatrix} \quad (7)$$

Consistency analysis is used to measure the consistency after weight results are found. This analysis shows whether there is an error in the work done or the result is consistent within itself. The following steps are taken to calculate the consistency rate [21, 22].

1. In order to calculate the consistency ratio, firstly the comparison matrix and the weight matrix are multiplied to obtain the T column vector.

$$T = \begin{bmatrix} k_{11} & k_{12} & \cdots & k_{1n} \\ k_{21} & k_{22} & \cdots & k_{2n} \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ k_{n1} & k_{n2} & \cdots & k_{nn} \end{bmatrix} x \begin{bmatrix} a_1 \\ a_2 \\ \cdot \\ \cdot \\ \cdot \\ a_n \end{bmatrix} = \begin{bmatrix} t_1 \\ t_2 \\ \cdot \\ \cdot \\ \cdot \\ t_n \end{bmatrix} \quad (8)$$

2. After obtaining the T vector, basic value elements are obtained by dividing each element of the T vector by the weight vector A of the T vector.

$$E_i = \frac{t_i}{a_i} \quad i = 1,2,\ldots,n \quad (9)$$

3. The arithmetic mean of these elements gives the basic value of pair wise comparison of this problem λ.

$$\lambda = \frac{\sum_{i=1}^{n} E_i}{n} \quad (10)$$

4. After obtaining λ, consistent indicator Cl should be obtained.

$$CI = \frac{\lambda - n}{n - 1} \quad (11)$$

5. The following formula is used to calculate the consistency ratio at the last step.

$$CR = \frac{CI}{RI} \quad (12)$$

The result is consistent if the consistency ratio (CR) is less than 0.1. If it exceeds 0.1, either there is a mistake in applying the AHP, or the operation is inconsistent.

In this study, AHP application was made using the Super Decisions software and the consistency ratio for all comparisons were found less than 0.1.

6. Heating system selection using Analytic Hierarchy Process (AHP)

For selecting the best heating system alternative for indoor-use, according to the results of QFD, customer demands with high importance values are the criteria for AHP. These are operating costs, to be easy to use, appearance, comfort, and saving energy. Also, the alternatives for the selection process are floor heating systems, radiator, air-condition, and fan-coil.

6.1. Comparing the alternatives

After the purpose, criteria and alternatives have determined, binary comparisons have done with 3 different experts from the sector and the academia. After all of binary comparisons have completed, the averages of their views are entered to Super Decisions software as shown in Table 3-8. After all of data have entered the program, lastly the result can be found as shown in Table 9.

Table 3. Comparing the alternatives according to the "saving energy" criteria.

	Radiator	Fan-Coil	Floor Heating	Air-Condition
Radiator	1	1/3	1/4	3
Fan-Coil	3	1	1/2	2
Floor Heating	6	4	1	5
Air-Condition	1/3	1/4	1/5	1

Table 4. Comparing the alternatives according to the "appearance" criteria.

	Radiator	Fan-Coil	Floor Heating	Air-Condition
Radiator	1	1/4	1/8	1/3
Fan-Coil	4	1	1/6	2
Floor Heating	8	6	1	6
Air-Condition	3	1/2	1/6	1

Table 5. Comparing the alternatives according to the "to be easy to use" criteria.

	Radiator	Fan-Coil	Floor Heating	Air-Condition
Radiator	1	1/4	1/5	1/4
Fan-Coil	4	1	1/3	2
Floor Heating	5	3	1	3
Air-Condition	4	1/2	1/3	1

Table 6. Comparing the alternatives according to the "operating costs" criteria.

	Radiator	Fan-Coil	Floor Heating	Air-Condition
Radiator	1	1/3	1/5	2
Fan-Coil	3	1	1/3	2
Floor Heating	5	3	1	4
Air-Condition	1/2	1/2	1/4	1

Table 7. Comparing the alternatives according to the "comfort" criteria.

	Radiator	Fan-Coil	Floor Heating	Air-Condition
Radiator	1	1/4	1/6	1/3
Fan-Coil	4	1	1/3	2
Floor Heating	6	3	1	5
Air-Condition	3	1/2	1/5	1

Table 8. Comparing the alternatives.

	Saving Energy	Operating Costs	Appearance	Comfort	To Be Easy To Use
Saving Energy	1	2	3	3	4
Operating Costs	1/2	1	4	3	5
Appearance	1/3	1/4	1	1/4	1/3
Comfort	1/3	1/3	4	1	3
To Be Easy To Use	1/4	1/5	3	1/3	1

Table 9. AHP results.

Alternatives	Total	Normal	Ideal	Ranking
Radiator	0.0537	0.1075	0.2002	4
fan-coil	0.1214	0.2428	0.4521	2
floor heating	0.2685	0.5370	10.000	1
air-condition	0.0564	0.1128	0.2101	3

As a result, according to the criteria and the evaluation, the most appropriate heating system is floor heating system (53.7%), then fan-coil (24.28%), air-condition (11.28%), and radiator (10.75%), respectively.

7. Conclusion

Heating systems directly affect customers' comfort and life quality; therefore construction companies must pay attention to quality and market research. For this reason several techniques were developed for several purposes; using QFD methodology, customer demands are emphasized and the technical requirements are listed and the comparison can be made. Using the AHP methodology, the decision maker can make decisions according to the criteria and the alternatives.

In this study, firstly QFD analysis has done for the heating systems and with this analysis, customer demands, technical requirements, correlation between them, and the technical importance have determined. For the purpose of satisfying these technical requirements and customer demands, some heating system alternatives have evaluated and prioritized using AHP.

The general limitation of the proposed model is the costly and exhausting information requested from experts (approx. 105 pairwise comparisons per one expert). Other limitations of the model are the preferences of the expert including uncertainty and conflicts and there is often needed more than one expert to make decisions.

According to the results, the most appropriate heating system alternative is floor heating system (53.7%), then fan-coil (24.28%), air-condition (11.28%) and radiator (10.75%), respectively. Also we have to say that, this is the first paper in the literature that combines QFD with AHP methodology in the heating system sector. As a further research, we think to improve this study with fuzzy numbers and also we consider combining QFD with other selection methodologies, such as Analytic Network Process (ANP), TOPSIS and ELECTRE. Besides, we will compare the results that found in this paper.

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