COMPUTATIONAL RESEARCH PROGRESS IN APPLIED SCIENCE & ENGINEERING (CRPASE)

CRPASE: TRANSACTIONS OF APPLIED SCIENCES

Journal homepage: http://www.crpase.com

CRPASE: Transactions of Applied Sciences 8 (1) Article ID: 2751, 1–8, March 2022

ISSN 2423-4591

Research Article

Check for updates

Extended Residential Heating System Selection Using Interval Type-2 Fuzzy Analytic Network Process with the Perspective of Energy

Sahika Ozdemir[1*], Kemal Gokhan Nalbant[2], Yavuz Ozdemir[3]

[1] *Department of Interior Architecture and Environmental Design, Istanbul Sabahattin Zaim University, Istanbul, Turkey*
[2] *Department of Software Engineering, Beykent University, Istanbul, Turkey*
[3] *Department of Industrial Engineering, Istanbul Health and Technology University, Istanbul, Turkey*

Keywords

Energy saving,
Heating systems,
Housing warming,
Decision making,
IT2 FANP.

Abstract

The need for energy increases due to the increasing population and developing technology. The limited energy resources pose incredible difficulties in meeting this rising energy consumption. Heating systems have essential in people's lives in terms of comfort. The design of the systems is critical for people to benefit from these systems under comfortable and economic conditions. In the previous papers, the alternatives of the residential heating system were evaluated using the generalized Choquet integral method with trapezoidal fuzzy numbers [1]. In this paper, the authors assess the alternatives for the residential heating system using an Interval Type-2 Fuzzy ANP methodology. The membership value of Type-2 Fuzzy sets can minimize the effects of uncertainties and vagueness. These sets make it probable to model uncertainties directly. The originality of the study comes from the first-time usage of IT2 FANP methodology in prioritizing the alternatives of residential heating systems. To the authors' knowledge, this is the first paper in the literature that uses IT2 FANP methodology in this field. The IT2 FANP methodology and the generalized Choquet integral methodology are compared in this study. Therefore, the ranking of alternatives is found as A4 (Radiator Heating Systems) > A3 (Fan Coil Heating Systems) > A1 (Unvented Fuel-Fired Heaters) in both methods. But the first and the second system alternative ranking are displaced as A2 (HVAC Systems)>A5 (Floor Heating Systems) in IT2 FANP methodology, whereas A5 (Floor Heating Systems) > A2 (HVAC Systems) in the generalized Choquet integral methodology with close weights.

1. Introduction

As the needs increase in our developing world, we consume our resources according to the demands. The environment, society, and place we live in are essential. Humans reduce the need for shelter, warming, and consumption by using the available resources. We need this to make our environment sustainable and livable to leave a sustainable life to future generations.

With technology development and increasing needs, alternatives to residential heating systems have also changed over time. Residential heating systems with different fuel types and many types of heating have a great reason to be preferred with their other features. While heating with coal is one of the most preferred residential heating systems from the past to the present, the central

* Corresponding Author: Sahika Ozdemir
E-mail address: sahika.ozdemir@izu.edu.tr, ORCID: https://orcid.org/0000-0002-5762-1962

Received: 6 March 2022; Revised: 22 March 2022; Accepted: 24 March 2022
https://doi.org/ 10.52547/crpase.8.1.2751

Academic Editor: **Muhammad Ammar Khan**

Please cite this article as: S. Ozdemir, K. Gokhan Nalbant, Y. Ozdemir, Extended Residential Heating System Selection Using Interval Type-2 Fuzzy Analytic Network Process with the Perspective of Energy, Computational Research Progress in Applied Science & Engineering, CRPASE: Transactions of Mechanical Engineering 8 (2022) 1–8, Article ID: 2751.

system, which emerged with the effects of time and technology, brought a different dimension to the residential heating systems. The demand for centralized system heating systems has intensified since the old coal stoves require a lot of human labor and heat only one room. There may be a central system or multiple residential heating systems. Those who choose the heat of their home or company may find it challenging to select the best and most profitable residential heating systems. While making these choices, it is essential to select the heating system that is the least harmful to the environment and has low energy consumption.

Heating systems, in general, are the systems that provide thermal comfort in the spaces by compensating for the heat losses occurring between the indoor and outdoor environments. These systems are essential in terms of ease in people's lives. The design of the systems is necessary for people to benefit from these systems under comfortable and economic conditions.

Decision-making problems are encountered in many areas. Problems with multiple criteria and choosing one of the alternatives are Multiple Criteria Decision-Making (MCDM) problems. Many studies using MCDM methods can be found in the literature [2-6].

In this paper, we applied an IT2 FANP methodology to find the best alternative for the residential heating system. In the literature, this is the first paper that uses the IT2 FANP method to select heating systems.

Many studies on Fuzzy Analytic Network Process (FANP) Methodology solve MCDM problems. Kang et al. [7] improved a FANP technique and applied it to facilitate decision-making. Dargi et al. [8] improved a FANP approach comprising the most critical factors for supplier selection in an Iranian automotive industry. Govindan et al. [9] proposed a FANP model for barrier evaluation in automotive parts remanufacturing towards cleaner production. Hemmati et al. [10] developed a FANP model and applied it to a sulfuric acid production plant. Nalbant et al. [11] evaluated inclusive campus environment design criteria using the Fuzzy Analytical Network Process (FANP) and Consistent Fuzzy Preference Relations (CFPR) techniques.

Karnik, Mendel, and Liang [12], Mendel, John and Liu [13], Boran and Akay [14], Sola et al. [15] have contributed to the literature for the development of IT2 FSs.

There are not many studies in the literature solved with FANP Method with IT2 FSs. Senturk et al. [16] proposed FANP with the IT2 fuzzy sets method by modifying Buckley’s approach with IT2 FSs. Wu and Liu [17] proposed a FANP methodology with IT2 FSs to evaluate the Enterprise Technology Innovation Ability (ETIA). Senturk et al. [18] modeled a Third-party Logistics company selection problem with an IT2 FANP technique with the main criteria of benefit, opportunities, cost, and risk (BOCR). Ozdemir et al. [19] found a new hybrid model based on Interval Type-2 Fuzzy Analytic Network Process (IT2 FANP) and Interval Type-2 Fuzzy TOPSIS (IT2 Fuzzy TOPSIS) for the evaluation of store plan alternatives produced with rule-based design method. Ozdemir et al. [20] prioritized store plan alternatives by IT2 FANP method and the best store plan alternative was selected.

This article is organized as follows: a short explanation about residential heating systems is given in the ‘‘Residential Heating Systems’’ section. In the third section, an application of the IT2 FANP method to prioritize residential heating system alternatives is made. Finally, the "Conclusion" section that concludes the article discusses comparing outcomes and future research directions.

2. Residential Heating Systems

In today's modern buildings, air conditioning control is extremely important due to both the ventilation problems and the rapid increase in air pollution.

The building sector realizes about 45% of energy use in the world. As energy is used for services to provide comfort conditions such as heating, cooling, ventilation in buildings, various energy consumption levels are involved throughout the entire building life cycle, from raw material acquisition to demolition and destruction of the building. Therefore, significant reductions in the construction sector also contribute significantly to the decrease in total energy consumption.

Various building design optimization studies were carried out in accordance with the energy performance legislation and building environmental assessment plans. Optimization methods used in these studies take into account both low emission levels and energy efficiency performance by changing different properties of buildings, and while doing this, they try to minimize energy consumption and costs [21]. Financial constraints and significant uncertainties in this retrofit problem, such as climate change, government policy change, and building occupant behavior, can easily influence the choice between proposed measures and thus define the success of adjustments. It is certain that the complex set of interactions between all components of a building and its environment must be taken into account in finding the most energy efficient solution that meets the needs of energy and non-energy issues such as financial, legal and social factors [22].

When space heating systems are examined, it is seen that hot water heating systems are the most preferred systems in terms of comfort. In hot water heating systems, energy is obtained by burning gas, liquid, or solid fuels in the boiler, and this energy is used for heating water. The heated water is conveyed to the place using heat emitters such as radiators, fan coils, air appliances, and floor heating pipes with the help of a pump. Thus, the heat transfer between these devices and the space increases the temperature of the room [23].

- **Unvented fuel-fired heaters**

In solid fuel systems used for heating or steam boiler applications, the ignition must be carried out in the boiler. Ignition is carried out with preferred materials to ignite fuel. For this reason, boiler systems have a cooking zone. After the fire is lit in the furnace, this continuously supported fire is fed with fuel at intervals. Boiler systems operating with solid fuel provide some essential advantages. As the central system is primarily preferred for central heating, heating can be performed more efficiently. So these systems provide both fast and efficient heating. Thanks to the steps such as insulation and protection, very high energy saving can be achieved and easy to use. Maintenance and cleaning operations are carried out very quickly, and boilers have a very high safety during use.

- **Heating Ventilating and Air Conditioning (HVAC) systems**

HVAC is a system that includes heating, ventilation, and air conditioning. While providing comfort conditions at maximum level, it also balances moisture and bacteria rates in the air.

- **Electric integrated systems, heat pumps**

Fan Coil units contain batteries as a fan and heat transfer surface. The heated air taken from the room with the help of a fan and passed over the batteries is blown back into the room. The water returning to the center by the return pipes is reheated and circulated here. For this purpose, circulation pumps are used. It has wide usage areas such as commercial, social buildings and residences like hotels, offices, stores, restaurants, and homes. It offers safe, economical, and practical solutions for heating. Since it is ready for installation from the factory, it can be used after electrical, and installation connections are made. Low maintenance and repair costs increase the reason for preference. Floor and ceiling fan coils reduce humidity by heating the air in apartments and villas. Fan Coil systems do not have ventilation, so they can only heat or cool.

- **Radiator heating systems**

Radiator systems are the leading systems used in heating spaces in buildings. In these applications, the thermal comfort of the room, the position of the radiators in the space, the materials used on the heating surfaces, the heating surface areas, the operating temperature depends on the parameters such as obstacles positioned around the radiators.

In radiator heating systems, the application is carried out using distribution via a pipe network. Round-trip pipes are laid from each collector box to each radiator through the screed in this distribution. The heating pipes are passed through the larger diameter protective spiral sheath pipes so that they do not damage the screed and the floor due to expansion during operation at high temperature (70 to 90 degrees), so that the space for development between the protective spiral sheath pipe and the heating pipe remains. This air volume also provides thermal insulation and prevents unnecessary heating and heat loss of the pipes [24].

- **Floor heating systems**

In recent years, floor heating systems that have increased their usage in public places and spaces (such as mosques, baths, saunas, greenhouses, roads, etc.) and private spaces such as houses are designed to provide a more comfortable heat distribution with less energy.

Floor heating systems are heating systems that dissipate the heat losses in the spaces by dissipating the energy it receives from the heat source with the pipes in the floor concrete under the floor and the floor and therefore the environment. The main principle of the system is that the amount of energy to meet the heat loss in a calculated volume is met by circulating the hot water supplied from a central producer through special pipes under the flooring material. Warm water is spread over the entire flooring area for homogeneous heating [25].

A more homogenous temperature distribution is provided horizontally and vertically in a space heated by the underfloor heating system. Underfloor heating system, the air on the floor rises towards the top of the space. As it grows, the air moves towards the upper parts of the space, weakening and cooling the air. Thus, hot air does not accumulate on the ground but on the living space, not on the upper parts of the space. This uniform temperature distribution from floor to ceiling is optimal for a theoretically ideal heat dissipation profile [25]

3. An IT2 FANP Application: Evaluation of Heating System Alternatives

The linguistic terms and their trapezoidal IT2 fuzzy scales of importance are listed in Table 1 [26]. In this paper, we apply the IT2 FANP technique [16] found to select the best heating system alternative. After that, the result of this method is compared with the previous study [1].

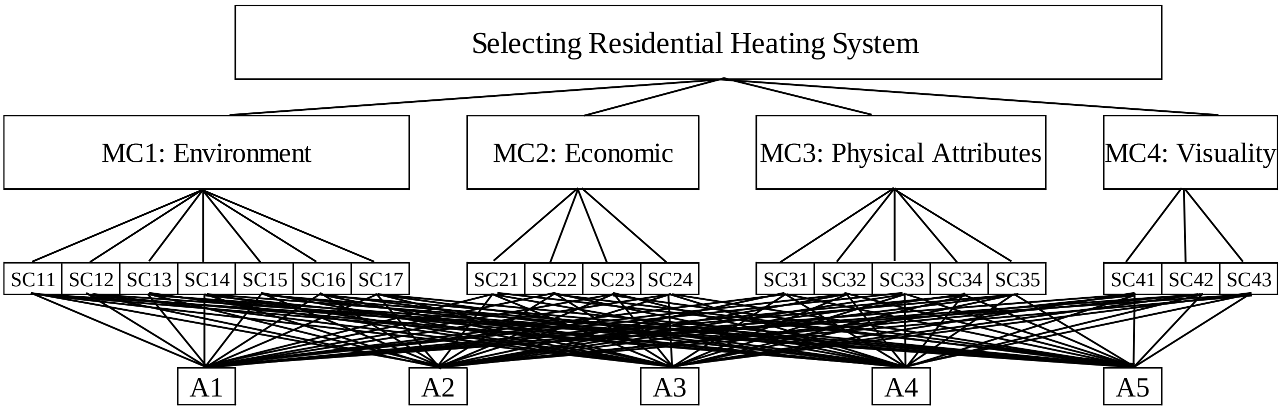

Figure 1. Hierarchy of the selection problem

The architect, the civil engineer, and the mechanical engineer needed to determine the best heating system alternative for a residential. Decision criteria and the main criteria were environment, economic, physical attributes, and visuality. The arrows in Figure 1 represent the hierarchy of the problem.

alternatives were defined by decision-makers for this problem, as seen in Figure 1. In this paper,

Environment criteria (MC1) include sub-criteria about environmental issues: "Energy Saving (SC11)", "Ecologic (SC12)", "Environmentally Friendly (SC13)", "Green and

Sustainable (SC14)", "Continuousness (SC15)", "Negative Impacts (SC16)", and "Low CO2 Emission (SC17)".

Economic criteria (MC2) include sub-criteria about costs: "Installation Cost (SC21)", "The Period of Use and Operation (SC22)", "Maintenance Cost (SC23)", and "Price Stabilization (SC24)".

Physical Attributes criteria (MC3) include the following sub-criteria: "Effective Usage (SC31)", "Heating and Cooling Load (SC32)", "Sizing (SC33)", "Ability to Work in Low Temperatures (SC34)", and "System Reliability (SC35)".

Visuality criteria (MC4) include the following sub-criteria: "The Purpose of Use of The Building (SC41)", "Planning Module (SC42)", and "Hidden Devices and Pipes (SC43)".

The heating systems alternatives are "Unvented Fuel-Fired Heaters" (A1), "HVAC Systems" (A2), "Fan Coil Heating Systems" (A3), "Radiator Heating Systems" (A4), and "Floor Heating Systems" (A5).

To solve the problem using IT2 FANP methodology, we make the comparisons with decision-makers using Interval Type 2 fuzzy scales as shown in Table 1.

Fuzzy pairwise comparison matrices between criteria (main, sub) are shown in Table 2, Table 3, respectively. Dma, Dmb, and Dmc denote the comparisons of decision-maker-A, decision-maker-B, and decision-maker-C in these tables. The values in this table are the same as those in Table 2 of the previous paper [1].

Table 1. Linguistic Terms.

Linguistic Terms	Trapezoidal IT2 fuzzy scales
Exactly Equal (E)	(1,1,1,1;1,1) (1,1,1,1;1,1)
Slightly Strong (S)	(1,2,4,5;1,1) (1.2,2.2,3.8,4.8;0.8,0.8)
Fairly Strong (F)	(3,4,6,7;1,1) (3.2,4.2,5.8,6.8;0.8,0.8)
Very Strong (V)	(5,6,8,9;1,1) (5.2,6.2,7.8,8.8;0.8,0.8)
Absolutely Strong (A)	(7,8,9,9;1,1) (7.2,8.2,8.8,9;0.8,0.8)

Table 2. Fuzzy pairwise comparison matrix among main criteria.

	MC1			MC2			MC3			MC4		
	Dma	Dmb	Dmc	Dma	Dmb	Dmc	Dma	Dmb	Dmc	Dma	Dmb	Dmc
MC1	E	E	E	S	S	S	S	E	F	E	S	S
MC2	1/S	1/S	1/S	E	E	E	S	1/S	S	1/S	E	E
MC3	1/S	E	1/F	1/S	S	1/S	E	E	E	1/S	S	1/S
MC4	E	1/S	1/S	S	E	E	S	1/S	S	E	E	E

Table 3. Fuzzy pairwise comparison matrix among subcriteria.

	SC11			SC12			SC13			SC14			SC15			SC16			SC17		
	Dma	Dmb	Dmc	Dma	Dmb	Dmc	Dma	Dmb	Dmc	Dma	Dmb	Dmc	Dma	Dmb	Dmc	Dma	Dmb	Dmc	Dma	Dmb	Dmc
SC11	E	E	E	E	1/S	E	E	1/S	S	S	S	S	S	S	S	S	S	S	S	S	S
SC12	E	S	E	E	E	E	E	1/S	S	S	S	S	S	S	S	S	S	S	S	S	S
SC13	E	S	1/S	E	S	1/S	E	E	E	E	S	E	E	S	E	E	F	E	E	S	E
SC14	E	S	1/S	E	E	1/S	E	1/S	E	E	E	E	E	S	E	E	F	E	E	E	E
SC15	E	E	1/S	E	1/S	1/S	E	1/S	E	E	1/S	E	E	E	E	E	S	E	E	1/S	E
SC16	E	1/S	1/S	E	1/F	1/S	E	1/F	E	E	1/F	E	E	1/S	E	E	E	E	E	1/F	E
SC17	E	S	1/S	E	E	1/S	E	1/S	E	E	E	E	E	S	E	E	F	E	E	E	E
SC21	1/S	S	1/F	1/S	E	1/F	1/S	1/S	1/S	1/S	E	1/S	1/S	SS	1/S	1/S	F	1/S	1/S	E	1/S
SC22	1/S	1/S	1/F	1/S	1/F	1/F	1/S	1/F	1/S	1/S	1/F	1/S	1/S	1/S	1/S	1/S	E	1/S	1/S	1/F	1/S
SC23	1/S	E	1/F	1/S	1/S	1/F	1/S	1/S	1/S	1/S	1/S	1/S	1/S	E	1/S	1/S	S	1/S	1/S	1/S	1/S
SC24	1/S	E	1/F	1/S	1/S	1/F	1/S	1/S	1/S	1/S	1/S	1/S	1/S	E	1/S	1/S	S	1/S	1/S	1/S	1/S
SC31	1/S	S	1/S	1/S	E	1/S	1/S	1/S	E	1/S	E	E	1/S	S	E	1/S	F	E	1/S	E	E
SC32	1/S	S	1/F	1/S	E	1/F	1/S	1/S	1/S	1/S	E	1/S	1/S	S	1/S	1/S	F	1/S	1/S	E	1/S
SC33	1/S	1/S	1/F	1/S	1/F	1/F	1/S	1/F	1/S	1/S	1/F	1/S	1/S	1/S	1/S	1/S	E	1/S	1/S	1/F	1/S
SC34	1/S	E	1/S	1/S	1/S	1/S	1/S	1/S	E	1/S	1/S	E	1/S	E	E	1/S	S	E	1/S	1/S	E
SC35	1/S	E	1/S	1/S	1/S	1/S	1/S	1/S	E	1/S	1/S	E	1/S	E	E	1/S	S	E	1/S	1/S	E
SC41	E	1/S	1/F	E	1/F	1/F	E	1/F	1/S	E	1/F	1/S	E	1/S	1/S	E	E	1/S	E	1/F	1/S
SC42	E	S	1/F	E	E	1/F	E	1/S	1/S	E	E	1/S	E	S	1/S	E	F	1/S	E	E	1/S
SC43	E	S	1/F	E	E	1/F	E	1/S	1/S	E	E	1/S	E	S	1/S	E	F	1/S	E	E	1/S

Table 4. Fuzzy pairwise comparison matrix among subcriteria (continued).

	SC21			SC22			SC23			SC24			SC31			SC32			SC33		
	Dma	Dmb	Dmc	Dma	Dmb	Dmc	Dma	Dmb	Dmc	Dma	Dmb	Dmc	Dma	Dmb	Dmc	Dma	Dmb	Dmc	Dma	Dmb	Dmc
SC11	S	1/S	F	F	F	F	F	F	F	F	F	F	S	1/S	S	S	1/S	F	S	S	F
SC12	S	1/S	F	F	F	F	F	F	F	F	F	F	S	1/S	S	S	1/S	F	S	S	F
SC13	S	S	S	S	F	S	S	S	S	S	S	S	S	S	E	S	S	S	S	F	S
SC14	S	E	S	S	F	S	S	S	S	S	S	S	S	S	E	S	S	S	S	F	S
SC15	S	1/S	S	S	F	S	S	S	S	S	S	S	S	S	E	S	S	S	S	F	S
SC16	S	1/F	S	S	F	S	S	S	S	S	S	S	S	S	E	S	S	S	S	F	S
SC17	S	E	S	S	F	S	S	S	S	S	S	S	S	S	E	S	S	S	S	F	S
SC21	E	E	E	E	F	E	E	S	E	E	S	E	S	E	1/S	S	E	S	S	F	S
SC22	E	1/F	E	E	E	E	E	1/S	E	E	1/S	E	S	1/F	1/S	S	E	S	S	F	S
SC23	E	1/S	E	E	S	E	E	E	E	E	E	E	S	1/S	1/S	S	E	S	S	F	S
SC24	E	1/S	E	E	S	E	E	E	E	E	E	E	S	1/S	1/S	S	E	S	S	F	S
SC31	1/S	E	S	1/S	F	S	1/S	S	S	1/S	S	S	E	E	E	E	E	S	E	F	S
SC32	1/S	E	1/S	1/S	F	1/S	1/S	S	1/S	1/S	S	1/S	E	E	1/S	E	E	E	E	F	E
SC33	1/S	1/F	1/S	1/S	E	1/S	1/S	1/S	1/S	1/S	1/S	1/S	E	1/F	1/S	E	1/F	E	E	E	E
SC34	1/S	1/S	S	1/S	S	S	1/S	E	S	1/S	E	S	E	1/S	E	E	1/S	S	E	S	S
SC35	1/S	1/S	S	1/S	S	S	1/S	E	S	1/S	E	S	E	1/S	E	E	1/S	S	E	S	S
SC41	S	1/F	1/S	S	E	1/S	S	1/S	1/S	S	1/S	1/S	S	1/F	1/S	S	1/F	E	S	E	E
SC42	S	E	1/S	S	F	1/S	S	S	1/S	S	S	1/S	S	E	1/S	S	E	E	S	F	E
SC43	S	E	E	S	F	E	S	S	E	S	S	E	S	E	1/S	S	E	S	S	F	S

Table 5. Fuzzy pairwise comparison matrix among subcriteria (continued).

	SC34			SC35			SC41			SC42			SC43		
	Dma	Dmb	Dmc	Dma	Dmb	Dmc	Dma	Dmb	Dmc	Dma	Dmb	Dmc	Dma	Dmb	Dmc
SC11	S	E	S	S	E	S	E	S	F	E	1/S	F	E	1/S	F
SC12	S	E	S	S	E	S	E	S	F	E	1/S	F	E	1/S	F
SC13	S	S	E	S	S	E	E	F	S	E	S	S	E	S	S
SC14	S	S	E	S	S	E	E	F	S	E	S	S	E	S	S
SC15	S	S	E	S	S	E	E	F	S	E	S	S	E	S	S
SC16	S	S	E	S	S	E	E	F	S	E	S	S	E	S	S
SC17	S	S	E	S	S	E	E	F	S	E	S	S	E	S	S
SC21	S	S	1/S	S	S	1/S	1/S	F	S	1/S	E	S	1/S	E	E
SC22	S	S	1/S	S	S	1/S	1/S	F	S	1/S	E	S	1/S	E	E
SC23	S	S	1/S	S	S	1/S	1/S	F	S	1/S	E	S	1/S	E	E
SC24	S	S	1/S	S	S	1/S	1/S	F	S	1/S	E	S	1/S	E	E
SC31	E	S	E	E	S	E	1/S	F	S	1/S	E	S	1/S	E	S
SC32	E	S	1/S	E	S	1/S	1/S	F	E	1/S	E	E	1/S	E	1/S
SC33	E	1/S	1/S	E	S	1/S	1/S	F	E	1/S	E	E	1/S	E	1/S
SC34	E	E	E	E	E	E	1/S	S	S	1/S	1/S	S	1/S	1/S	S
SC35	E	E	E	E	E	E	1/S	S	S	1/S	1/S	S	1/S	1/S	S
SC41	S	1/S	1/S	1/S	1/S	1/S	E	E	E	E	1/F	E	E	1/F	1/S
SC42	S	S	1/S	1/S	1/S	1/S	E	F	E	E	E	E	E	E	1/S
SC43	S	S	1/S	1/S	1/S	1/S	E	F	S	E	E	S	E	E	E

The geometric mean of the main criteria and subcriteria can be seen in Tables 4 and 5, respectively.

Table 4. The geometric mean of main criteria.

MC1	1	2	2.3	3	1	1	1	2	2	3	1	1
MC2	1	1	0.9	1	1	1	1	1	1	1	1	1
MC3	0	1	0.8	1	1	1	0	1	1	1	1	1
MC4	1	1	1.2	1	1	1	1	1	1	1	1	1
Total	3	4	5.3	7	1	1	3	4	5	6	1	1
Reciprocal	0	0	0	0	1	1	0	0	0	0	1	1

Table 5. The geometric mean of subcriteria.

SC11	1.1	2	3	3	1	1	1	2	3	3	1	1
SC12	1.1	2	3	3	1	1	1	2	3	3	1	1
SC13	1	2	2	3	1	1	1	2	2	3	1	1
SC14	0.9	1	2	2	1	1	1	1	2	2	1	1
SC15	0.8	1	2	2	1	1	1	1	2	2	1	1
SC16	0.8	1	2	2	1	1	1	1	2	2	1	1
SC17	0.9	1	2	2	1	1	1	1	2	2	1	1
SC21	0.6	1	1	2	1	1	1	1	1	2	1	1
SC22	0.4	1	1	1	1	1	0	1	1	1	1	1
SC23	0.4	1	1	1	1	1	0	1	1	1	1	1
SC24	0.4	1	1	1	1	1	0	1	1	1	1	1
SC31	0.6	1	1	2	1	1	1	1	1	2	1	1
SC32	0.4	0	1	1	1	1	0	0	1	1	1	1
SC33	0.3	0	1	1	1	1	0	0	1	1	1	1
SC34	0.4	1	1	1	1	1	0	1	1	1	1	1
SC35	0.4	1	1	1	1	1	0	1	1	1	1	1
SC41	0.4	0	1	1	1	1	0	0	1	1	1	1
SC42	0.6	1	1	1	1	1	1	1	1	1	1	1
SC43	0.7	1	1	2	1	1	1	1	1	2	1	1
Total	12	17	27	35	1	1	13	18	26	33	1	1
Reciprocal	0	0	0	0	1	1	0	0	0	0	1	1

The main criteria and subcriteria's fuzzy weights are calculated and shown in Tables 6 and 7, respectively.

Table 6. The fuzzy weight of the main criteria.

MC1	0	0	0.6	1	1	1	0	0	1	1	1	1
MC2	0	0	0.3	0	1	1	0	0	0	0	1	1
MC3	0	0	0.2	0	1	1	0	0	0	0	1	1
MC4	0	0	0.3	1	1	1	0	0	0	0	1	1

Table 7. The fuzzy weight of the subcriteria.

SC11	0	0	0	0	1	1	0	0	0	0	1	1
SC12	0	0	0	0	1	1	0	0	0	0	1	1
SC13	0	0	0	0	1	1	0	0	0	0	1	1
SC14	0	0	0	0	1	1	0	0	0	0	1	1
SC15	0	0	0	0	1	1	0	0	0	0	1	1
SC16	0	0	0	0	1	1	0	0	0	0	1	1
SC17	0	0	0	0	1	1	0	0	0	0	1	1
SC21	0	0	0	0	1	1	0	0	0	0	1	1
SC22	0	0	0	0	1	1	0	0	0	0	1	1
SC23	0	0	0	0	1	1	0	0	0	0	1	1
SC24	0	0	0	0	1	1	0	0	0	0	1	1
SC31	0	0	0	0	1	1	0	0	0	0	1	1
SC32	0	0	0	0	1	1	0	0	0	0	1	1
SC33	0	0	0	0	1	1	0	0	0	0	1	1
SC34	0	0	0	0	1	1	0	0	0	0	1	1
SC35	0	0	0	0	1	1	0	0	0	0	1	1
SC41	0	0	0	0	1	1	0	0	0	0	1	1
SC42	0	0	0	0	1	1	0	0	0	0	1	1
SC43	0	0	0	0	1	1	0	0	0	0	1	1

After the local weights of the alternatives are found, the fuzzy weights are aggregated, as seen in Table 8.

Table 8. The fuzzy weights of alternatives.

A1											
0.00	0.01	0.08	0.39	1.00	1.00	0.00	0.01	0.06	0.26	0.80	0.80
A2											
0.01	0.03	0.38	1.54	1.00	1.00	0.01	0.04	0.30	1.11	0.80	0.80
A3											
0.00	0.02	0.16	0.76	1.00	1.00	0.00	0.02	0.13	0.53	0.80	0.80
A4											
0.00	0.02	0.21	0.91	1.00	1.00	0.01	0.03	0.16	0.64	0.51	0.51
A5											
0.01	0.03	0.26	1.14	1.00	1.00	0.01	0.03	0.21	0.81	0.51	0.51

Then, Type-2 fuzzy numbers are defuzzified using the DTraT method [26], as seen in Table 9.

Table 9. Results of the application using IT2 FANP methodology.

	Weights	Normalized Values
A1	0.100	7.98%
A2	0.418	33.42%
A3	0.199	15.95%
A4	0.236	18.91%
A5	0.297	23.74%

According to the results in Table 9, the defuzzified overall values of alternative residential heating systems using IT2 FANP methodology are obtained as 0.100, 0.418, 0.199, 0.236, and 0.297. The ranking order of alternatives from the best to the worst is A2, A5, A4, A3, and A1.

The results of the IT2 FANP methodology and the comparison with the generalized Choquet integral methodology results are given in Table 10.

Table 10. Comparison of the results with the generalized Choquet integral.

	IT2 FANP			The generalized Choquet Integral		
	Weight	Normalized Value	Ranking	Weight	Normalized Value	Ranking
A1	0.100	7.98%	5	0.330	13.03%	5
A2	0.418	33.42%	1	0.582	23.00%	2
A3	0.199	15.95%	4	0.489	19.31%	4
A4	0.236	18.91%	3	0.517	20.44%	3
A5	0.297	23.74%	2	0.613	24.22%	1

10. Conclusions

In our rapidly depleting world, population growth, globalization, rapid development in technology, increase in income and welfare level, and rapid increase in energy demand and consequently, ecosystem balance deterioration caused new approaches not only in protecting the environment but also in energy use. If the current production is insufficient to meet the increasing energy demand, new investments are made, and this need is tried to be completed. However, the energy deficit can be met primarily by investments in energy efficiency.

Energy-saving minimizes energy consumption by evaluating energy wastes and preventing current energy losses without reducing quality and performance. Energy saving is realized in two ways. First, using direct energy-saving homes, cars and other cutting-edge technologies; It consists of concrete measures such as adjusting habits and daily behaviors. The second is indirect energy savings, reducing the production of new goods by ensuring that existing goods are used longer; measures such as regulating settlements to minimize energy consumption, using technologies that consume less energy.

To ensure energy efficiency, insulation to buildings, use of efficient heating-cooling systems, architectural evaluation of natural lighting applications etc. applications can be counted. In today's modern buildings, air conditioning control is extremely important due to both ventilation problems and rapid air pollution increase.

The IT2 FANP methodology and the generalized Choquet integral methodology are compared in this study. At the end of the evaluation process, this methodology using the IT2 fuzzy scales has selected the most suitable outcome as “HVAC systems”. The ranking of the other alternatives is A5, A4, A3, and A1, respectively. According to the previous result, the ranking is obtained as A5, A2, A4, A3 and A1 in Choquet integral methodology. Therefore, the ranking of alternatives is found as A4>A3>A1 in both methods. But the first and the second system alternative ranking are displaced as A2 (HVAC Systems)>A5 (Floor Heating Systems) in IT2 FANP methodology whereas A5 (Floor Heating Systems) > A2 (HVAC Systems) in the generalized Choquet integral methodology with close weights.

Trapezoidal fuzzy numbers were used instead of fuzzy triangular numbers at Choquet Integral calculation steps [1]. The reason for the variations in the weights, normalized values, and the rankings (Table 10) can be thought of as at Choquet integral calculation steps, alternatives are scored independently of each other, whereas, in IT2 FANP calculation steps, alternatives are pairwise compared with each other according to the subcriteria. For this reason, in IT2 FANP steps, trapezoidal IT2 fuzzy scales are used, which gives better results for daily usage.

When these results are evaluated, it would be correct to say that choosing Alternative A2 (HVAC Systems) is the most reasonable result, and then the others. The main advantage of this paper is to handle uncertainties and vagueness better.

Regarding future research, the problem can be evaluated with other MCDM methodologies, and more solutions could be compared for the evaluation processes of residential heating system alternatives. Also, intelligent software that automatically calculates solutions could be developed.

Conflict of Interest Statement

The authors declare that they have no conflicts of interest/competing interests.

References

[1] Y. Ozdemir and S. Ozdemir, Residential heating system selection using the generalized Choquet integral method with the perspective of energy, Energy & Environment 30 (2019) 121–140.
[2] Y. Ozdemir, Y and K.G. Nalbant, Personnel selection for promotion using an integrated consistent fuzzy preference relations-fuzzy analytic hierarchy process methodology: A real case study, Asian Journal of Interdisciplinary Research 3 (2020) 219–236.
[3] P. Chowdhury and S.K. Paul, Applications of MCDM methods in research on corporate sustainability: A systematic literature review, Management of Environmental Quality: An International Journal, (2020).
[4] I.M. Hezam, M.K. Nayeem, A. Foul and A.F. Alrasheedi, COVID-19 Vaccine: A neutrosophic MCDM approach for determining the priority groups, Results in physics 20 (2021) 103654.
[5] S. Ozdemir, K.G. Nalbant and Y. Ozdemir, Evaluating Campus Components According To The Inclusive Design Principles Using An Integrated Consistent Fuzzy Preference Relations And Grey Relational Analysis Methodology, Computational Research Progress in Applied Science & Engineering, Transactions of Civil and Environmental Engineering 7 (2021) 1–5.
[6] T. Tan, G. Mills, E. Papadonikolaki and Z. Liu, Combining multi-criteria decision making (MCDM) methods with building information modelling (BIM): A review, Automation in Construction 121 (2021) 103451.
[7] H.Y. Kang, A.H. Lee and C.Y. Yang, A fuzzy ANP model for supplier selection as applied to IC packaging, Journal of Intelligent Manufacturing 23 (2012) 1477–1488.
[8] A. Dargi, A. Anjomshoae, M.R. Galankashi, A. Memari and M.B.M. Tap, Supplier selection: A fuzzy-ANP approach, Procedia Computer Science 31 (2014) 691–700.
[9] K. Govindan, K.M. Shankar and D. Kannan, D. Application of fuzzy analytic network process for barrier evaluation in automotive parts remanufacturing towards cleaner production–a study in an Indian scenario, Journal of Cleaner Production 114 (2016) 199–213.
[10] N. Hemmati, M.R. Galankashi, D.M. Imani and H. Farughi, Maintenance policy selection: a fuzzy-ANP approach, Journal of Manufacturing Technology Management 29 (2018) 1253–1268.
[11] K.G. Nalbant, S. Ozdemir and Y. Ozdemir, Evaluating Inclusive Campus Environment Design Criteria Using CFPR and FANP Methodologies, WSEAS Transactions on Computer Research 9 (2021) 92–102.
[12] N.N. Karnik, J.M. Mendel and Q. Liang, Type-2 fuzzy logic systems, IEEE Transactions on Fuzzy Systems 7 (1999) 643–658.
[13] J.M. Mendel, R.I John and F. Liu, Interval type-2 fuzzy logic systems made simple, IEEE Transactions on Fuzzy Systems 14 (2006) 808–821.
[14] F.E. Boran and D. Akay, A generic method for the evaluation of interval type-2 fuzzy linguistic summaries, IEEE Transactions On Cybernetics 44 (2013) 1632–1645.
[15] H.B. Sola, J. Fernandez, H. Hagras, F. Herrera, M. Pagola and E. Barrenechea, Interval type-2 fuzzy sets are generalization of interval-valued fuzzy sets: toward a wider view on their relationship, IEEE Transactions on Fuzzy Systems 23 (2014) 1876–1882.
[16] S. Senturk, Y. Binici and N. Erginel, The theoretical structure of fuzzy analytic network process (FANP) with interval type-2 fuzzy sets, IFAC-PapersOnLine 49 (2016) 1318–1322.
[17] T. Wu and X. Liu, An interval type-2 fuzzy ANP approach to evaluate enterprise technological innovation ability, Kybernetes, 45(9)(2016) 1486–1500.
[18] S. Senturk, N. Erginel and Y. Binici, Interval Type-2 Fuzzy analytic network process for modelling a third-party logistics (3PL) company, Journal of Multiple-Valued Logic & Soft Computing 28 (2017).
[19] Y. Ozdemir, S. Ozdemir and K.G. Nalbant, A Hybrid Methodology for Prioritizing of Store Plan Alternatives Produced with Rule-Based Design, International Journal of Information Technology & Decision Making 20 (2021) 1685–1709.
[20] S. Ozdemir, K.G. Nalbant and Y. Ozdemir, An Interval Type-2 Fuzzy Analytic Network Process For Prioritizing of Store Plan Alternatives Produced With Ruled Based Design, CRPASE: Transactions of Applied Sciences 7 (2021) 1–5.
[21] M. Fesanghary, S. Asadi and Z.W. Geem, Design of low-emission and energy-efficient residential buildings using a multi-objective optimization algorithm, Build Environ 49 (2012) 245–250.
[22] Z. Ma, P. Cooper, D. Daly and L. Ledo, Existing building retrofits: Methodology and state-of-the-art, Energy Build 55 (2012) 889–902.
[23] K. Ucler, A. Kibar, B. Karabag and K.S. Yigit, Experimental investigation of obstacles placed around radiators under window, Electronic Journal of Machine Technologies 12 (2015) 61–69.
[24] S. Gencler, Fundamentals of heating installation technique, Viessmann Akadamie, 2011.
[25] M. Arici, D. Dil and H. Karabay, The effect of pipe distance and water temperature on soil surface temperature in underfloor heating applications, TMMOB Chamber of Mechanical Engineers Journal of Plumbing Engineering, 116 (April-May)(2010) 52–56.
[26] C. Kahraman, B. Oztaysi, I.U. Sari and E. Turanoglu, Fuzzy analytic hierarchy process with interval type-2 fuzzy sets, Knowledge-Based Systems 59 (2014) 48–57.