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Energy Piles Design Parameters Optimization by using Fuzzy Logic

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Abstract

Energy pile uses environmental-friendly technology, i.e. low carbon footprint and greenhouse gas (GHG) emissions, and cost-effective. The use of energy piles have been increasingly grown due to the combination of their transferring load from structure into the bearing layer and exchanging of heat with the soil, i.e. environmental benefits. Energy Piles are used renewable energy designed to utilize the relative constant temperature of the soil (soil energy: geothermal) that surrounds the energy piles for heating and cooling of buildings by the use of ground source heat pump (GSHP). Energy piles have been harvesting energy from the soil that surrounds the piles by using buried pipe networks which aims to reduce their carbon footprint and to increase the energy efficiency of the building, i.e. to have energy-efficient building. In the study the design parameters of energy piles (diameter/size/length of pile and type of foundation, length/diameter/thickness/location of pipe pattern inside energy piles, dimensions & the arrangement/pattern of energy piles and pipes, type of concrete, and fluid characteristics inside pipes, power & location of GSHP, diameter & length of energy piles, soil thermal properties & soil temperature, groundwater level, depth to bedrock, type of concrete, type of GSHP, type of fluid inside pipes, pipe configuration inside energy piles…, i.e. all related design parameters) that affect their design of energy pile and related pipes are evaluated by using fuzzy logic. The thermal efficiency of energy piles improves significantly by increasing the number & configuration of pipes inside the energy piles and by adding thermally conductive materials to the concrete within acceptable limits. By using Fuzzy method; the calculated criteria weights for energy piles design parameters' weights are as follows: the most important evaluation dimension/main-criteria is "Soil thermal properties & Soil temperature", the second important evaluation dimension is "Pipe configuration inside Energy Piles" and the third important evaluation dimension is "Diameter & length of energy piles". By using energy piles buildings will have minimum carbon footprint and will be environmental-friendly green buildings.

1. Introduction

Energy consumption of buildings has become a relevant international issue, and various design strategies have been developed to enhance energy saving in many countries. Today, Buildings' responsibility for approximately 40% of total energy consumption and over 30% of greenhouse gas emissions has shifted global interest toward the so-called "Nearly zero energy buildings" (NZEB). The design of an NZEB has the purpose of constructing buildings with less energy consumption and low carbon emission. The development of energy geo-structures contributes to this goal as applying shallow geothermal energy in geo-structures for space cooling and heating of buildings. This environmentally friendly technology can be applied to all types of soil-embedded structures such as the diaphragm walls, tunnels, shallow foundations, and piles.

In Europe, 75% of the residential energy consumption is used for heating and cooling of buildings. In addition, the global energy demand for the cooling of buildings has increased by 70% due to global warming. Integrating heat exchanger pipes with structural foundations in one system has created a new renewable solution for buildings' thermal loads. However, the interaction between thermal and geotechnical loads makes their design more complex and challenging.

In the study, the key parameters that affect their design concerning the energy piles' dimensions are examined, the arrangement of pipes, concrete admixture, and fluid characteristics. The thermal efficiency of energy piles improves significantly by increasing the number of pipes inside the piles and by adding thermally conductive materials to the concrete within acceptable limits.

In the past years, an increasing number of energy geostructure projects have been implemented in many countries where they have achieved a cumulative share of carbon dioxide savings worldwide. The Laizer tunnel in Vienna (Austria), the Keble College in Oxford (UK), the Dock Midfield terminal at Zurich airport in Switzerland, and the Wuxi Guolian Tower in China are some applications for various types of energy geo-structures in the world. Among all these types, the energy pile remains the most common application for the ground heat exchange process. It takes advantage of the relative stability of underground temperature below a depth of 15m–50m to extract or reject heat from/to the ground. The heat transfer is carried out in an energy pile through ground heat exchanger (GHE) pipes installed along their reinforcement cage, where the heat transfer fluid (HTF) circulates and exchanges heat with the surrounding. Despite the rapid spread of this technology, especially in the UK and Austria, energy piles' installation still faces considerable challenges due to the interaction between thermal and geotechnical design.

Piles are structural foundation components that are relatively long and usually slender and transport loads from superstructures to deep layers of soil. Due to the enormous amounts of energy used for different purposes nowadays, the significance of energy conservation is being emphasized more and more. The building industry consumes a significant portion of energy (more than 30%) globally. Deep foundations/piles have underutilized geothermal mass, which can absorb and store soil's temperature/energy better than many other materials. For little additional construction cost, the energy loops of a heat exchange system/pipes (energy pipes) are buried in the concrete piles.

Energy piles are new technology that consist of pile foundations combined with closed-loop ground sourced heat pump (GSHP) systems by using energy pipes. Their purpose is to provide support to the building, as well as acting as a heat source and a heat sink. In effect, the thermal mass of the ground enables the building to store unwanted heat from cooling systems and allows heat pumps to warm the building in winter.

Figure 1. Building with energy piles

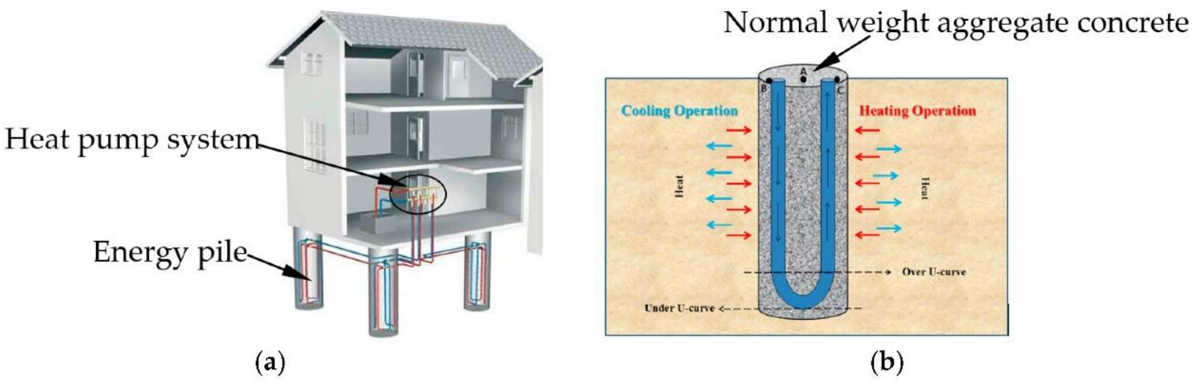

Figure 2. Energy system detail inside energy pile

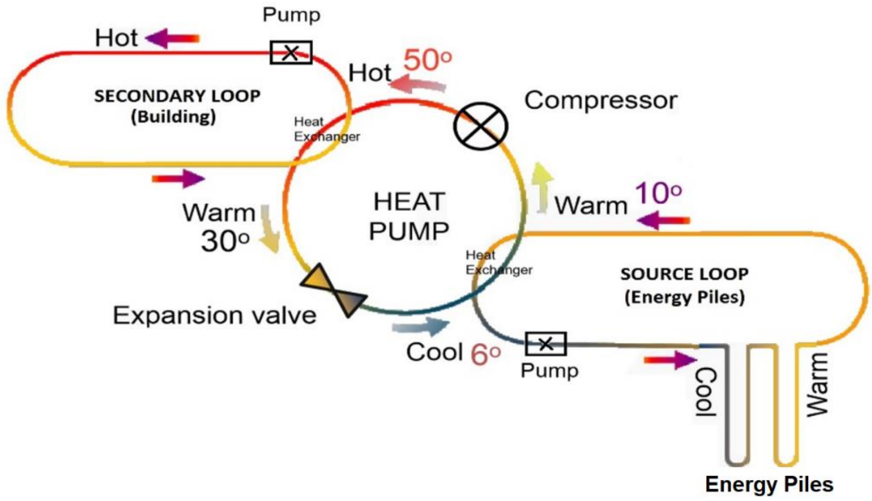

Figure 3. Schematic drawing of ground sourced heat pump and its related energy loop

Energy pile's loop systems are connected via heat exchangers to the internal heating and cooling distribution systems of the building, the details of them are presented in Figure 2 and Figure 3. A modest amount of electricity is required to drive the pumps. In the system there is no combustion, and the loop system has an advantage over traditional natural gas and oil heating systems. Carbon and greenhouse gas emissions as well as local pollutants are materially reduced.

Ground source heat pump systems will make an important contribution to renewable energy as they lead to both energy efficiencies in buildings and are compatible with moving away from fossil fuels as lower carbon sources of electricity become available. The use of energy piles has been increasingly grown across the world due to the combination of their traditional role as bearing elements and their environmental benefits. In US, the 80x50 energy program is developed in New York City, demands an 80% reduction in carbon emissions by 2050. In January 2016 the New York City passed a law requiring all government buildings to investigate geothermal options, starting in 2017.

2. Material and Method

In the study; an integrated Fuzzy AHP- Fuzzy TOPSIS- Fuzzy VIKOR approaches are used to assess/evaluate energy piles design parameters optimization factors. In literature Fuzzy Multi Criteria Decision Making Methods (FMCDM) are used in different fields by many researchers (Klir, 1995; Buckley, 1985, Chen vd, 1992; Chan vd, 2007; Kumar, vd, 2016; Satrovic, 2018; Shukla, 2014; Wang, 2015; Incekara 2019; Incekara 2020; Incekara 2018; Incekara 2021; Incekara 2022; Incekara 2023) by using MATLAB program.

2.1. Fuzzy Multi Criteria Decision Making Methods (FMCDM)

In literature Fuzzy Multi Criteria Decision Making Methods (FMCDM) are used in different fields by many researchers and Fuzzy AHP & Fuzzy TOPSIS are also used in many sectors, i.e. evaluation of energy piles' design parameters. The evaluation of energy piles design parameters optimization, to evaluate parameters, to evaluate the criteria for human resource for science and technology, for analyzing customer preferences, to evaluate risk analysis in green supply chain, and to select machine tools.

2.2. Fuzzy AHP Method

Since the standard AHP method does not include the possibility of situations with ambiguity in the estimation, it is possible to upgrade this method with fuzzy approach. This approach is called the Fuzzy AHP method. Instead of one defined value, in the Fuzzy AHP method full range of values that include unsafe attitudes of decision maker should be generated. For that process it is possible to use triangular fuzzy numbers, trapezoidal or Gaussian fuzzy numbers. The Fuzzy AHP method suggests their application directly in criteria pairs comparison matrix. Triangular fuzzy numbers are used in most cases/problems by many researchers in literature because of this reason in the study triangular fuzzy numbers method is used in Fuzzy AHP method. A triangular fuzzy number that is defined in R set can be described as $\tilde{N}=(l, n, u)$ where l is the minimum, n is the most possible and u is the maximum value of a fuzzy case. Its triangular membership function is characterized below which is presented in Figure 4 and in equation (1).

$$\mu\tilde{N}(x) = \begin{cases} (x-l)/(n-l), & l \leq x \leq n \\ (x-u)/(n-u), & n \leq x \leq u \\ 0, & x < l \text{ or } x > u \end{cases} \quad (1)$$

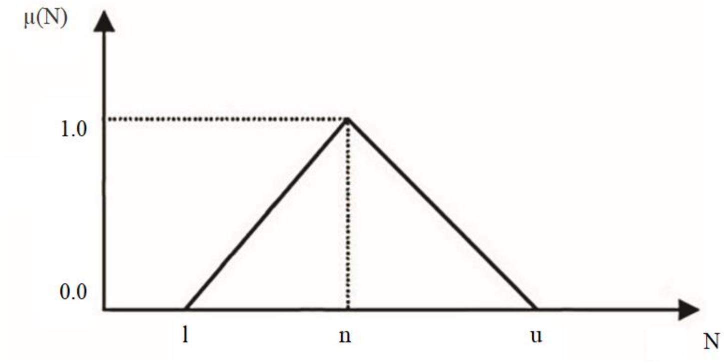

Figure 4. Triangular fuzzy number

Triangular fuzzy number Ñ (shown in Figure 1) can be described as an interval of real numbers where each of them has a degree of belonging to the interval between 0 and 1. Triangular fuzzy number is defined with three real numbers, expressed as l, n and u. In the study the performance of each scenario to each criterion is introduced as a fuzzy number. And in the study the ratings of qualitative criteria are considered as linguistic variables. These linguistic variables can be expressed in positive triangular fuzzy numbers as described in Table 1.

Table 1. Linguistic variables for the alternatives

Linguistic Terms-Abbreviation	Linguistic Variables	Triangular Fuzzy Numbers
SDA	Strongly Disagree	(0, 0, 0.15)
DA	Disagree	(0.15, 0.15, 0.15)
LDA	Little Disagree	(0.30, 0.15, 0.20)
NC	No Comment	(0.50, 0.20, 0.15)
LA	Little Agree	(0.65, 0.15, 0.15)
A	Agree	(0.80, 0.15, 0.20)
SA	Strongly Agree	(1, 0.20, 0)

After forming a matrix of fuzzy criteria comparison it should be defined vector of criteria weights W. For that purpose, the following equations/steps were used in the study.

Let X ={x1, x2,..., xm } be an object set, and G={g1, g2,...,gn} be a goal set. N extent analysis values for each object can be obtained as $N_{gi}^{1}, N_{gi}^{2}, \ldots, N_{gi}^{n}$ i= 1,2,…n

Step 1: The values of fuzzy extensions for the i-th object are given in Expression (2);

$$Si = \sum_{j=1}^{n} N_{gi}^{j} \otimes \left[\sum_{i=1}^{m}\sum_{j=1}^{n} N_{gi}^{j}\right]^{-1} \quad (2)$$

In order to obtain the expression $\left[\sum_{i=1}^{m}\sum_{j=1}^{n} N_{gi}^{j}\right]$ it is necessary to perform additional fuzzy operations with n values of the extent analysis, which is represented in Equation (3) and (4);

$$\sum_{j=1}^{n} N_{gi}^{j} = \left(\sum_{j=1}^{n} lj, \sum_{j=1}^{n} nj, \sum_{j=1}^{n} uj\right) \quad (3)$$

$$\left[\sum_{i=1}^{m}\sum_{j=1}^{n} N_{gi}^{j}\right] = \left(\sum_{i=1}^{m} li, \sum_{i=1}^{m} ni, \sum_{i=1}^{m} ui\right) \quad (4)$$

And it is required to calculate the inverse vector above by using Expression (5);

$$\left[\sum_{i=1}^{m}\sum_{j=1}^{n} N_{gi}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{m} ui}, \frac{1}{\sum_{i=1}^{m} ni}, \frac{1}{\sum_{i=1}^{m} li}\right) \quad (5)$$

Step 2: While N1 and N2 are triangular fuzzy numbers, the degree of possibility for N2≥N1 is defined as:

$$V(N2 \geq N1) = \text{supy} \geq x\ \left(\min(\mu N_1(x),\ \mu N_2(y)\right) \quad (6)$$

It can be represented in the following manner by Expression (7):

$$V\ (N2 \geq N1) = \text{hgt}\ (N2 \cap N1)\ \mu N2(d) \quad (7)$$

$$= \begin{cases} 1, & \text{if } n_2 \geq n_1 \\ 0, & \text{if } l_1 \geq l_2 \\ \frac{(l_1 - u_2)}{(n_2 - u_2)(m_1 - l_1)}, & \text{otherwise} \end{cases} \quad (8)$$

Where d is the ordinate of the highest intersection point D between μN1 and μN2.
To compare μN1 and μN2, values of both, V(N2 ≥ N1) and V(N1 ≥ N2) are needed.

Step 3: The degree of possibility for a convex fuzzy number to be greater than k convex numbers Ni (i=1,2,...,k) can be defined by expression (9);

$$V\ (N \geq N1, N2,..., Nk) = V[(N \geq N1), (N \geq N2), \dots, (N \geq Nk)] \quad (9)$$
$$= \min V\ (N \geq Ni=1,2,3,\dots,k$$

Assume that Expression (10) is;

$$d'\ (Ai) = \min V\ (Si \geq Sk) \quad (10)$$

for k=1,2,...,n; k ≠ i. So the weight vector is obtained by Expression (11);

$$W' = (d'(A1), d'(A2),..., d'(Am))T \quad (11)$$

where, Ai (i =1,2,...,n) consists of n elements.

Step 4: Through normalization, the weight vectors are reduced to Expression (12);

$$W = (d(A1), d(A2),..., d(An))T \quad (12)$$

where W represents an absolute number.

2.3. Fuzzy TOPSIS Method

The fuzzy TOPSIS calculation most important step is given in Equation (13), i.e. Creating the Decision Matrix; aggregated ratings are calculated by using Equation (13):

$$\tilde{V}ij = \frac{1}{2}\ [\tilde{v}_{ij}^{1} \oplus \tilde{v}_{ij}^{2}\ \oplus \dots\ \tilde{v}_{ij}^{s}\ ] \quad (13)$$

where $\tilde{v}_{ij}^{s}$ is the performance rating value obtained from s-th decision maker.
The basic steps of proposed fuzzy TOPSIS method can be described as follows:

Step 1: In the first step, a panel of decision makers (DMs) who are knowledgeable about supplier selection process is established. In a group that has K decision-makers (i.e. D1, D2, ..., Dk) are responsible for ranking (yjk) of each criterion (i.e. C1, C2, …, Cn) in increasing order. Then, the aggregated fuzzy importance weight for each criterion can be described as fuzzy triangular numbers $\tilde{v}j$ = (aj, bj, cj) for k = 1, 2, …, K and j = 1, 2, …, n. The aggregated fuzzy importance weight can be determined as follows:

$$dj = \min_{k}\ \{yjk\},\ bj = \frac{1}{K}\sum_{k=1}^{K} yjk,\ cj = \max_{k}\ \{yjk\} \quad (14)$$

Then, the aggregated fuzzy importance weight for each criterion is normalized as follows:

$\tilde{v}j$ = (aj1, bj2, cj3)

$$\text{where } vj1 = \frac{\frac{1}{dj}}{\sum_{j=1}^{n}\frac{1}{dj}},\ vj2 = \frac{\frac{1}{bj}}{\sum_{j=1}^{n}\frac{1}{bj}},\ vj3 = \frac{\frac{1}{cj}}{\sum_{j=1}^{n}\frac{1}{cj}} \quad (15)$$

Then the normalized aggregated fuzzy importance weight matrix is constructed as $\tilde{V}$ = ($\tilde{v}$1, $\tilde{v}$2, …, $\tilde{v}$n)

Step 2: A decision matrix is formed.

$$X = \begin{bmatrix} x11 & x12 & \cdots & x1n \\ x21 & x22 & \vdots & x2n \\ \cdots & \cdots & \cdots & \cdots \\ xm1 & xm2 & \ldots & xmn \end{bmatrix} \quad (16)$$

Step 3: After forming the decision matrix, normalization is applied. The calculation is done using equations 17 and 18.

$$rij = \frac{\frac{1}{xij}}{\sqrt{\sum_{i=1}^{m}\frac{1}{xij^2}}} \quad \text{for minimization objective, where i = 1, 2, ..., m and j = 1, 2, ..., n} \quad (17)$$

$$rij = \frac{xij}{\sqrt{\sum_{i=1}^{m} xij^2}} \quad \text{for maximization objective, where i = 1, 2, ..., m and j = 1, 2, ..., n} \quad (18)$$

Then, normalized decision matrix is obtained as:

$$R = \begin{bmatrix} r11 & r12 & \cdots & r1n \\ r21 & r22 & \vdots & r2n \\ \cdots & \cdots & \cdots & \cdots \\ rm1 & rm2 & \ldots & rmn \end{bmatrix} \quad (19)$$

Step 4: Considering the different weights of each criterion, the weighted normalized decision matrix is computed by multiplying the importance weight of evaluation criteria and the values in the normalized decision matrix. The weighted normalized decision matrix Ṽ for each criterion is defined as:

Ṽ = [Ṽij]mxn for i = 1, 2, ..., m and j = 1, 2, ..., n (20)

Where Ṽij = rij X õj
Here Ṽij denotes normalized positive triangular fuzzy numbers.

Step 5: Then fuzzy positive (Ã*) and fuzzy negative (Ã−) ideal solutions are determined as follows:

Ã* = (ṽ1*, ṽ2*, ..., ṽn*) where
$\tilde{V}j^* = \left\{\max_i(vij1), \max_i(vij2), \max_i(vij3)\right\}$ and
Ã- = (ṽ1-, ṽ2-, ..., ṽn-) where
$\tilde{V}j^- = \left\{\min_i(vij1), \min_i(vij2), \min_i(vij3)\right\}$
for i = 1, 2, ..., m and j = 1, 2, ..., n (21)

Step 6: Then the fuzzy distance of each alternative from fuzzy positive and fuzzy negative ideal solutions are calculated as:

$$\tilde{a}i^* = \sqrt{\sum_{j=1}^{n}(\tilde{v}_j^* - \tilde{v}_{ij}^*)} \quad \text{and} \quad \tilde{a}i^- = \sqrt{\sum_{j=1}^{n}(\tilde{v}_j^- - \tilde{v}_{ij}^-)} \quad i = 1, 2, ..., m \quad (22)$$

Step 7: Then the fuzzy closeness coefficient Ñ is determined as:

$$\tilde{N}i = \frac{\tilde{a}_i^-}{\tilde{a}_i^* + \tilde{a}_i^-} \quad i = 1, 2, ..., m \quad (23)$$

The fuzzy closeness represents the distances to the fuzzy positive ideal solution and the fuzzy negative ideal solution simultaneously.

Step 8: The fuzzy closeness coefficient defuzzified as follows:

$$Ni = \sqrt[3]{N_{i1} \cdot N_{i2} \cdot N_{i3}} \quad (24)$$

2.3. Selection of Energy Piles' Design Parameters Optimization Criteria: Dimensions and Evaluation Model

Evaluation of energy piles' design parameters optimization, i.e. measuring scale, consists of 8 dimensions-main criteria and 41 evaluation factors-sub-criteria are evaluated by decision makers (DMs). A questionnaire was developed following the methodology proposed for the below methods, which was answered by 32 experts/DMs.

In the study 8 main criteria, i.e. Diameter & length of energy piles (C1), Soil thermal properties & Soil temperature (C2), Groundwater level (C3), Depth to bedrock (C4), Type of Concrete (C5), Type of Ground Sourced Heat Pump (C6), Type of Fluid inside pipes (C7), Pipe configuration inside Energy Piles (C8) and 41 related subcriteria are evaluated/assessed by each expert/DM. For the case of prioritization of the criteria, after the aggregation process performed with the answers of the 32 experts, the comparison matrix was obtained. The pairwise comparison matrices for subcriteria and alternatives are calculated.

Subsequently, the normalized pairwise comparison matrix of criteria was obtained. The priority vector and the CR for the criteria were obtained. To obtain the other priorities, the same procedure presented for the criteria was applied. In order to facilitate the calculations; which enters the individual judgments of the experts and generates the local and global preferences of all levels of the hierarchical tree (criteria and subcriteria).

It uses sensor devices and gateway connectivity to derive actionable insights and use them to develop new and advanced services for enhanced productivity. It further improves real-time decision-making, complex operability, and overall experiences. Hereunder, evaluation of energy piles'design parameters' main criteria that are listed below and related sub-criteria are described.

C1. Diameter & length of energy piles
C2. Soil thermal properties & Soil temperature
C3. Groundwater level
C4. Depth to bedrock
C5. Type of Concrete
C6. Type of Ground Sourced Heat Pump
C7. Type of Fluid inside pipes
C8. Pipe configuration inside Energy Piles

2.4. Determining the evaluation criteria weights with Fuzzy AHP Approach

Firstly, each DM practiced pair-wise comparisons energy piles' design parameters' dimensions and evaluation factors by using fuzzy AHP. Using the survey data acquired from these experts, integrated pair-wise comparison matrices are formed by combining all expert opinions. Thus, the pair-wise comparison values are converted to triangular fuzzy numbers and fuzzy pair-wise comparison matrices are created, presented in Table 2.

$$\text{lij} = \text{mink}\{\text{aijk}\} \qquad \text{nij} = \frac{1}{\text{K}}\sum_{\text{j}=1}^{K} \text{b}_{ijk} \qquad \text{uij} = \text{maxk}\{\text{cijk}\} \tag{25}$$

Table 2. Fuzzy mutual criteria comparison

	C1	C2	C3	C4	C5	C6	C7	C8
C1	(1, 1, 1)	(3, 5, 7)	(1/5, 1/3, 1)	(1/9, 1/7, 1/5)	(1, 3, 5)	(1/9, 1/7, 1/5)	(5, 7, 9)	(1/9, 1/7, 1/5)
C2	(1/7, 1/5, 1/3)	(1, 1, 1)	(1/7, 1/5, 1/3)	(1, 3, 5)	(1/11, 1/9, 1/7)	(1/5, 1/3, 1)	(1/7, 1/5, 1/3)	(7, 9, 11)
C3	(1, 3, 5)	(3, 5, 7)	(1, 1, 1)	(1, 3, 5)	(5, 7, 9)	(1/7, 1/5, 1/3)	(7, 9, 11)	(7, 9, 11)
C4	(5, 7, 9)	(1/5, 1/3, 1)	(1/9, 1/7, 1/5)	(1, 1, 1)	(3, 5, 7)	(1/9, 1/7, 1/5)	(1/11, 1/9, 1/7)	(1/11, 1/9, 1/7)
C5	(1/5, 1/3, 1)	(1/11, 1/9, 1/7)	(1/9, 1/7, 1/5)	(1/7, 1/5, 1/3)	(1, 1, 1)	(1/9, 1/7, 1/5)	(1/7, 1/5, 1/3)	(1/7, 1/5, 1/3)
C6	(5, 7, 9)	(1, 3, 5)	(3, 5, 7)	(5, 7, 9)	(5, 7, 9)	(1, 1, 1)	(1/7, 1/5, 1/3)	(3, 5, 7)
C7	(1/9, 1/7, 1/5)	(3, 5, 7)	(1/11, 1/9, 1/7)	(7, 9, 11)	(3, 5, 7)	(1/11, 1/9, 1/7)	(1, 1, 1)	(1/7, 1/5, 1/3)
C8	(7, 9, 11)	(1/11, 1/9, 1/7)	(1/11, 1/9, 1/7)	(7, 9, 11)	(3, 5, 7)	(1/7, 1/5, 1/3)	(3, 5, 7)	(1, 1, 1)

After acquiring the fuzzy comparison matrices, importance weights of energy piles design parameters' dimensions; evaluation criteria is calculated by the FAHP method. According to the calculated criteria weights for energy piles design parameters' weights; the most important evaluation dimension/main-criteria is "Soil thermal properties & Soil temperature" with 0.185 importance weight, the second important evaluation dimension is "Pipe configuration inside Energy Piles" with 0.163 importance weight and the third important evaluation dimension is "Diameter & length of energy piles" with 0.152 importance weight.

2.5. Ranking the alternatives by Fuzzy TOPSIS methods

For the evaluation of energy piles' design parameters' factors, Fuzzy TOPSIS approach is conducted with the collected data of DM's surveys/interviews. Primarily, the linguistic variables of the alternatives are created. By the help of criteria weights, Fuzzy-TOPSIS method's steps are performed/completed and energy piles' design parameters that affect factors are ranked from the best to the worse. Primarily, the linguistic variables of the alternatives are created.

3. Results

Soil temperature measurements show that the ground temperature below approx. 6 meters depth remains relatively constant throughout the year. This is because of high thermal inertia of the soil. At the surface and in the ground there is a time lag between the temperature fluctuations. Therefore, at a sufficient depth, the ground temperature is always higher than that of the outside air in winter and is lower in summer. To utilize the geothermal temperature, energy piles are used.

After acquiring the fuzzy comparison matrices, importance weights of energy piles design parameters' dimensions; evaluation criteria is calculated by using Fuzzy method. According to the calculated criteria weights for energy piles design parameters' weights; the most important evaluation dimension/main-criteria is "Soil thermal properties & Soil temperature", the second important evaluation dimension is "Pipe configuration inside Energy Piles" and the third important evaluation dimension is "Diameter & length of energy piles".

4. Conclusion

Energy piles use environmental-friendly and climate-friendly technology, they are clean, cost-effective, space-efficient and quiet systems therefore they are very popular. They can be installed all type of foundations in the World. Only efficiency of them changes since it depends on the location of energy piles. The factor that affect the design and efficiency of energy piles are; thermal conductivity of soil types, humidity, depth below the ground surface, groundwater level, soil temperature, heat capacity of soil, depth to bedrock, thickness of the soil layer, soil temperature that changes with seasonal, i.e. mean earth temperature, thermal diffusivity of the soil, density of soil, rainfall and wind speed that leads to a reduction of the ground surface temperature. The soil temperature profiles that provide an indication of frost depth which can have an impact on spring snowmelt runoff rates is considered in the design of energy piles. Each rock type has a different thermal conductivity, which is a measure of the ability of a material to conduct heat. Rocks that are rich in quartz, like sandstone, have a high thermal conductivity and rocks that are rich in clay or organic material, like shale and coal, have low thermal conductivity, meaning that heat passes less readily through these layers. The other factors that affect the design of energy piles. Heat flow, which is affected from the items related with soil parameters that are listed above, is calculated by multiplying the geothermal gradient and the thermal conductivity.

The advantages of energy piles are stated below, i.e. HVAC system that use energy pile's GSHP and related energy piping system; Heating, cooling and hot water with one device, The resources are continuous, reliable, sustainable and clean, The cost of geothermal energy is not prone to fluctuation, It provides a large resource, readily available in one form or another in every country, It helps reduce dependence on fossil or nuclear fuels, It can be cost-competitive in providing base-load electricity, heating, cooling and hot water, There is diversity of use: electricity generation and direct use of heat, It can be used simultaneously for both power generation and direct-use applications, Low investment cost, Most efficient heating-cooling system, Economically beneficial in the long term, In heating 70% advantage compared with LPG, 75% economic/advantage compared with diesel, In cooling 40% economic compared with split air conditioner, No need to install outdoor facilities, chimney, fuel tank, etc., Minimum operating and maintenance requirements, For heating and cooling no extra unit is needed, i.e. radiator, fan coil, channel, underfloor heating etc., One ground sourced heat pump device is enough for heating and cooling, Piping embedded in the energy pile (Circulating water circulates within these piles), Reduces CO_2 emissions to the atmosphere, One of the cheapest energy source usage method, Installing energy piping inside the energy pile has low cost, Minimal impact on construction and piling program, 25. Provides a stable & sustainable renewable energy source to use in the building.

In the study by using Fuzzy method; the calculated criteria weights for energy piles design parameters' weights are as follows: the most important evaluation dimension/main-criteria is "Soil thermal properties & Soil temperature", the second important evaluation dimension is "Pipe configuration inside Energy Piles" and the third important evaluation dimension is "Diameter & length of energy piles".

By using energy piles, we can save energy cost up to 55%. If energy pile's locations are near geothermal area/locations, we can save energy cost of up to 70%. By using energy piles, we can reduce our building's operating costs, energy costs and CO_2 emissions compared with conventional heating systems. By using structural piles as energy piles, the piles under the building have dual functionality, i.e. structural and energy source.

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Conflicts of interest

The authors declare no conflicts of interest.

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