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Enhanced MCDM Methodology under Uncertainty: Applications to Energy Efficiency Evaluation of Mechanical and Electrical Systems in Public Buildings

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Abstract: Evaluation of Mechanical and Electrical systems in public Buildings is a multi-criteria decision-making problem that has various criteria. These criteria can affect energy efficiency. So, we aim to propose an MCDM method for rate the criteria importance and proposed a set of systems to select the best one in energy firms. This section can increase energy efficiency. We applied the ARAS methodology to rank the alternatives. The ARAS methodology is an MCDM method. It applied into criteria independent. The ARAS method is integrated under the plithogenic set to deal with the vague and uncertainty information. The plithogenic set is an extension of neutrosophic set and solves the uncertainty in the opinions of experts. Case study with seven criteria and ten systems are proposed in this study to select the best one. The results show the Energy Consumption Performance criterion has the highest score and System Maintenance and Operational Efficiency criterion has the lowest score. We compared the proposed method with other MCDM methos such as TOPSIS, VIKOR, EDAS and MABAC methos. The results show the proposed method is robust compared with other MCDM methods.

Keywords: Multi-Criteria Decision-Making; Uncertainty Framework; ARAS Method; Energy Efficiency; Public Buildings.

1. Introduction

Protecting the facility and its infrastructure is a big part of facilities management, and security is undoubtedly a crucial component of that. However, mechanical and electrical services are also essential to a building's protection in terms of offering a secure atmosphere, as well as to the building's suitability and capacity to house operations in a safe and efficient manner[1], [2].

A commercial property cannot operate without the safe and proper installation, testing, and monitoring of mechanical and electrical services, which are fundamental to any building's structure. Many small and medium-sized enterprises lack the funding necessary to hire in-house specialists in mechanical and electrical services[3], [4].

The mechanical systems connected with heating, ventilation, and air conditioning have progressed dramatically from the traditional steam-heating systems and general mechanical control methods. The range of systems and techniques employed today is far more intricate. The purpose of these more advanced systems is to give the building's occupants a secure, comfortable, and healthy atmosphere in addition to local control and energy saving, which the older systems were unable to do. Much work and technology has been developed to give both warmth and cooling. Evaluation of Mechanical and Electrical Systems in Public Buildings is a MCDM problem[5], [6].

Multi-criteria decision-making (MCDM) techniques are divided into two categories: multi-attribute and multi-objective. The former identifies the best options, while the latter identifies the best options that maximize the goal. To find the best answer to the decision-making problem, the MCDM approaches follow a set of phases[7], [8]. DM is the process of selecting the best option that, with the help of an expert, largely satisfies all the criteria; however, determining the weight of each criterion is vital. In certain situations, it is assumed that the criterion weights are equal, however this is not always the case. The criterion weight indicates the importance of the criteria, and it is therefore crucial to calculate the criterion weight[9], [10].

Researchers have recently created new plithogenic MCDM techniques. The plithogenic operators and the degree of contradiction are employed in these plithogenic decision-making models to determine the experts' collective opinion on the alternatives' criterion satisfaction rate[11], [12].

These days, a lot of people use computer-based technology to make their jobs easier. Similarly, Decision Support Systems (DSS) have been widely used in decision-making to facilitate management's decision-making process. Numerous DSS techniques have been used in a variety of spheres of life, including offices, commerce and economics, education, and so on[13], [14]. Thus, a decision assistance system was created to help decision makers to select the best alternative. The Additive Ratio Assessment (ARAS) approach was used in the development of this decision support system. Nowadays, a lot of different fields employ the ARAS approach to help with decision-making. The optimum option is selected by employing the ARAS approach while constructing a decision support system[15], [16].

The rest of this study is organized as follows: Section 2 shows the proposed methodology steps. Section 3 shows the case study results. Section 4 shows comparative analysis. Section 5 shows the conclusions.

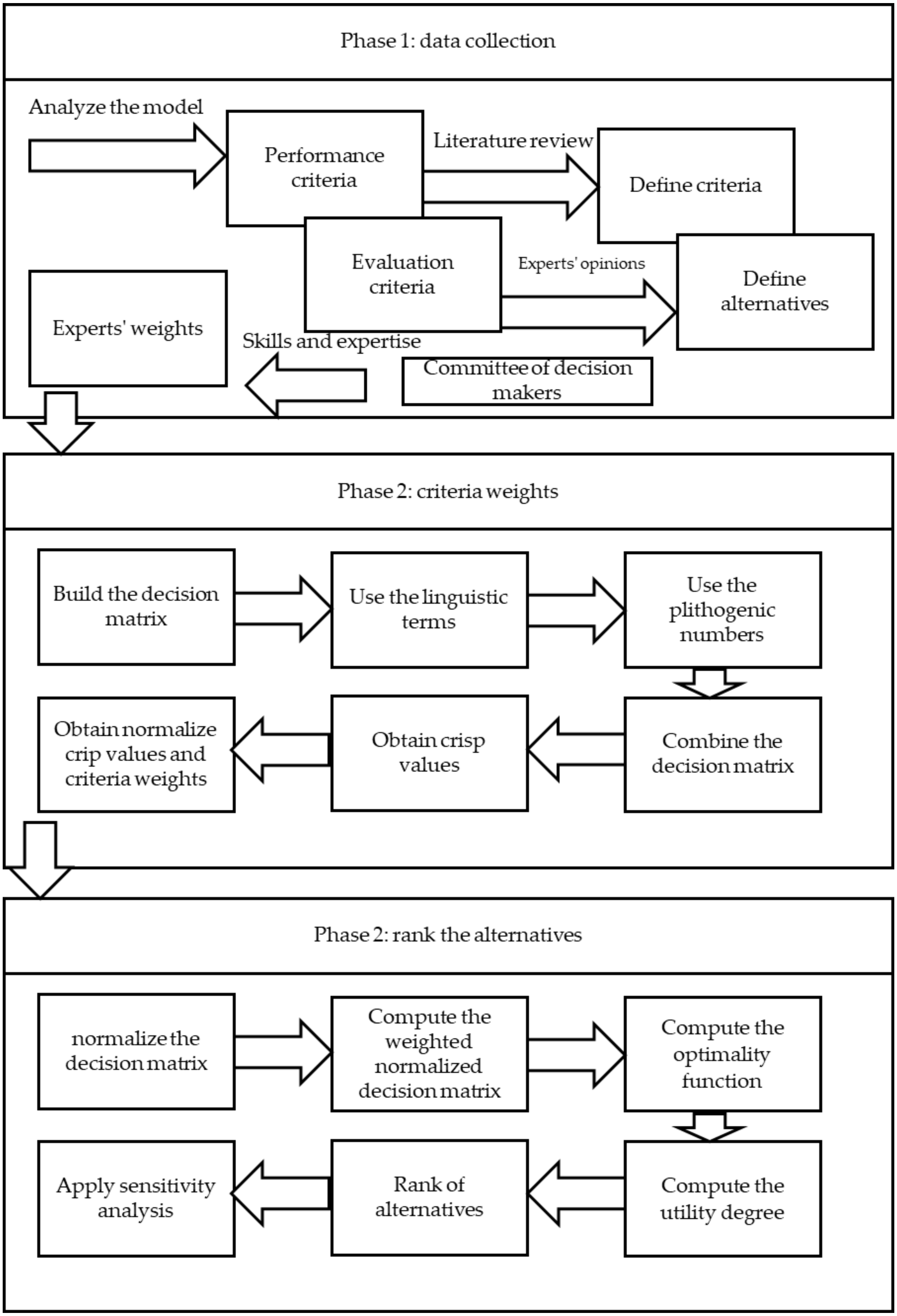
Phase 1: data collection
Analyze the model
Performance criteria
Literature review
Define criteria
Evaluation criteria
Experts' opinions
Define alternatives
Experts' weights
Skills and expertise
Committee of decision makers
Phase 2: criteria weights
Build the decision matrix
Use the linguistic terms
Use the plithogenic numbers
Obtain normalize crip values and criteria weights
Obtain crisp values
Combine the decision matrix
Phase 2: rank the alternatives
normalize the decision matrix
Compute the weighted normalized decision matrix
Compute the optimality function
Apply sensitivity analysis
Rank of alternatives
Compute the utility degree

Figure 1. The steps of the proposed methodology.

2. Methodology

The methodology of ARAS is used under the plithogenic set to find the ranking of alternatives[17], [18]. Figure 1 shows the steps of the proposed method. The steps involved in below:

Step 1. The initial decision matrix of order set of criteria and alternatives is built based on the opinions of experts and decision makers. The decision matrix contains the values of criteria and alternatives, these values are used from the linguistic terms such as medium, high, low. These terms have plithogenic numbers to evaluate the criteria and alternatives. Three decision makers and experts are used to creating the decision matrix. The combined decision matrix is obtained from the plithogenic intersection operators based on the representation fuzzy and neutrosophic sets of linguistic terms[19], [20].

Plithogenic fuzzy intersection

$$a \wedge F b. \tag{1}$$

Plithogenic intuitionistic fuzzy intersection

$$a_1 a_2 \wedge IFS b_1 b_2 = a_1 \wedge F b_1 a_2 \wedge F b_2 \tag{2}$$

Plithogenic neutrosophic intersection

$$a_1 a_2 a_3 \wedge P b_1 b_2 b_3 = a_1 \wedge F b_{112} a_2 \wedge F b_2 + a_2 \vee a_2 F b_2 a_3 \wedge F b_3 \tag{3}$$

$$a \wedge F b = ab, a \vee F = a + b - ab \tag{4}$$

Step 2. The weights of criteria are computed.

After aggregating the decision matrix. The crips values are computed using the score function. The normalized values of crips values are obtained to obtain the crisp values.

Step 3. After obtaining the criteria weights, we applied the steps of the Plithogenic ARAS method to rank the alternatives.

Step 3.1 normalize the decision matrix.

The decision matrix is normalized as:

$$y_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \tag{5}$$

Step 3.2 Compute the weighted normalized decision matrix.

The normalized decision matrix is multiplied by the criteria weights such as:

$$d_{ij} = y_{ij} * w_j \tag{6}$$

Step 3.3. Compute the optimality function

The optimality function is computed and better has the larger value.

$$E_i = \sum_{j=1}^{n} d_{ij} \tag{7}$$

Step 3.4 Compute the utility degree

The utility degree is computed as follows:

$$U_i = \frac{E_i}{V_o} \tag{8}$$

Where V_o is a optimality value of E_i

3.5 Rank of alternatives.

3. Application to Decision-Making for Evaluation of Mechanical and Electrical Systems in Public Buildings

The proposed plithogenic ARAS MCDM method is illustrated with the decision on the Evaluation of Mechanical and Electrical Systems in Public Buildings. Energy efficiency is very important for evaluating and selecting the best alternatives. We collected seven criteria and ten alternatives from previous studies as shown in Table 1.

Table 1. The decision-making environment includes ten alternatives and seven criteria that are used in this study.

Criteria	Alternatives
System Maintenance and Operational Efficiency	System 1
Indoor Environmental Quality	System 2
Energy Consumption Performance	System 3
Energy-Saving Technologies	System 4
Energy Monitoring and Data Analytics	System 5
Compliance with Energy Standards and Certifications	System 6
Renewable Energy Utilization	System 7
	System 8
	System 9
	System 10

The initial plithogenic numbers of three experts to evaluate the decision matrix are as follows:

Expert 1

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
A_1	(0.2 5, 0.6 0,	(0.4 0, 0.7 0,	(0.5 0, 0.4 0,	(0.6 5, 0.3 0,	(0.6 5, 0.3 0,	(0.2 5, 0.6 0,	(0.6 5, 0.3 0,
A_2	(0.9 5, 0.0 5,	(0.6 5, 0.3 0,	(0.2 5, 0.6 0,	(0.4 0, 0.7 0,	(0.5 0, 0.4 0,	(0.6 5, 0.3 0,	(0.5 0, 0.4 0,
A_3	(0.8 0, 0.1 0,	(0.5 0, 0.4 0,	(0.5 0, 0.4 0,	(0.6 5, 0.3 0,	(0.4 0, 0.7 0,	(0.5 0, 0.4 0,	(0.4 0, 0.7 0,
A_4	(0.6 5, 0.3 0,	(0.4 0, 0.7 0,	(0.6 5, 0.3 0,	(0.2 5, 0.6 0,	(0.2 5, 0.6 0,	(0.4 0, 0.7 0,	(0.2 5, 0.6 0,
A_5	(0.5 0, 0.4 0,	(0.2 5, 0.6 0,	(0.5 0, 0.4 0,	(0.6 5, 0.3 0,	(0.6 5, 0.3 0,	(0.2 5, 0.6 0,	(0.9 5, 0.0 5,
A_6	(0.4 0, 0.7 0,	(0.6 5, 0.3 0,	(0.4 0, 0.7 0,	(0.5 0, 0.4 0,	(0.5 0, 0.4 0,	(0.6 5, 0.3 0,	(0.6 5, 0.3 0,
A_7	(0.2 5, 0.6 0,	(0.5 0, 0.4 0,	(0.2 5, 0.6 0,	(0.4 0, 0.7 0,	(0.4 0, 0.7 0,	(0.5 0, 0.4 0,	(0.5 0, 0.4 0,
A_8	(0.1 0, 0.7 5,	(0.4 0, 0.7 0,	(0.8 0, 0.1 0,	(0.2 5, 0.6 0,	(0.2 5, 0.6 0,	(0.4 0, 0.7 0,	(0.4 0, 0.7 0,
A_9	(0.9 5, 0.0 5,	(0.2 5, 0.6 0,	(0.9 5, 0.0 5,	(0.9 5, 0.0 5,	(0.6 5, 0.3 0,	(0.2 5, 0.6 0,	(0.2 5, 0.6 0,
A_{10}	(0.8 0, 0.1 0,	(0.6 5, 0.3 0,	(0.5 0, 0.4 0,	(0.4 0, 0.7 0,	(0.2 5, 0.6 0,	(0.1 0, 0.7 5,	(0.6 5, 0.3 0,

Expert 2

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
A_1	(0.1 0, 0.7 5,	(0.4 0, 0.7 0,	(0.5 0, 0.4 0,	(0.6 5, 0.3 0,	(0.1 0, 0.7 5,	(0.2 5, 0.6 0,	(0.4 0, 0.7 0,
A_2	(0.2 5, 0.6 0,	(0.1 0, 0.7 5,	(0.2 5, 0.6 0,	(0.4 0, 0.7 0,	(0.5 0, 0.4 0,	(0.6 5, 0.3 0,	(0.1 0, 0.7 5,
A_3	(0.4 0, 0.7 0,	(0.1 0, 0.7 5,	(0.5 0, 0.4 0,	(0.6 5, 0.3 0,	(0.8 0, 0.1 0,	(0.1 0, 0.7 5,	(0.2 5, 0.6 0,
A_4	(0.5 0, 0.4 0,	(0.9 5, 0.0 5,	(0.4 0, 0.7 0,	(0.2 5, 0.6 0,	(0.1 0, 0.7 5,	(0.2 5, 0.6 0,	(0.4 0, 0.7 0,
A_5	(0.6 5, 0.3 0,	(0.1 0, 0.7 5,	(0.6 5, 0.3 0,	(0.1 0, 0.7 5,	(0.2 5, 0.6 0,	(0.4 0, 0.7 0,	(0.5 0, 0.4 0,
A_6	(0.4 0, 0.7 0,	(0.2 5, 0.6 0,	(0.1 0, 0.7 5,	(0.2 5, 0.6 0,	(0.4 0, 0.7 0,	(0.5 0, 0.4 0,	(0.6 5, 0.3 0,
A_7	(0.2 5, 0.6 0,	(0.4 0, 0.7 0,	(0.2 5, 0.6 0,	(0.4 0, 0.7 0,	(0.5 0, 0.4 0,	(0.6 5, 0.3 0,	(0.2 5, 0.6 0,
A_8	(0.1 0, 0.7 5,	(0.5 0, 0.4 0,	(0.4 0, 0.7 0,	(0.5 0, 0.4 0,	(0.6 5, 0.3 0,	(0.5 0, 0.4 0,	(0.4 0, 0.7 0,

A9	(0.95, 0.05,	(0.65, 0.30,	(0.50, 0.40,	(0.65, 0.30,	(0.65, 0.30,	(0.65, 0.30,	(0.50, 0.40,
A10	(0.80, 0.10,	(0.65, 0.30,	(0.65, 0.30,	(0.40, 0.70,	(0.25, 0.60,	(0.10, 0.75,	(0.65, 0.30,

Expert 3

	C1	C2	C3	C4	C5	C6	C7
A1	(0.25, 0.60,	(0.40, 0.70,	(0.50, 0.40,	(0.65, 0.30,	(0.80, 0.10,	(0.25, 0.60,	(0.40, 0.70,
A2	(0.95, 0.05,	(0.10, 0.75,	(0.25, 0.60,	(0.40, 0.70,	(0.50, 0.40,	(0.65, 0.30,	(0.65, 0.30,
A3	(0.80, 0.10,	(0.10, 0.75,	(0.50, 0.40,	(0.65, 0.30,	(0.80, 0.10,	(0.80, 0.10,	(0.80, 0.10,
A4	(0.65, 0.30,	(0.95, 0.05,	(0.40, 0.70,	(0.25, 0.60,	(0.10, 0.75,	(0.95, 0.05,	(0.65, 0.30,
A5	(0.50, 0.40,	(0.80, 0.10,	(0.65, 0.30,	(0.10, 0.75,	(0.25, 0.60,	(0.10, 0.75,	(0.95, 0.05,
A6	(0.40, 0.70,	(0.65, 0.30,	(0.50, 0.40,	(0.95, 0.05,	(0.25, 0.60,	(0.25, 0.60,	(0.10, 0.75,
A7	(0.25, 0.60,	(0.50, 0.40,	(0.65, 0.30,	(0.80, 0.10,	(0.40, 0.70,	(0.40, 0.70,	(0.25, 0.60,
A8	(0.10, 0.75,	(0.40, 0.70,	(0.80, 0.10,	(0.65, 0.30,	(0.50, 0.40,	(0.50, 0.40,	(0.40, 0.70,
A9	(0.95, 0.05,	(0.25, 0.60,	(0.95, 0.05,	(0.95, 0.05,	(0.65, 0.30,	(0.65, 0.30,	(0.50, 0.40,
A10	(0.80, 0.10,	(0.65, 0.30,	(0.50, 0.40,	(0.40, 0.70,	(0.25, 0.60,	(0.10, 0.75,	(0.65, 0.30,

We combine these plithogenic numbers into a single matrix using plithogenic operators. Then we apply the score function to obtain crisp values. Then we normalize the decision matrix using Eq. (5) as shown in Table 2.

Table 2. The normalized decision matrix

	C1	C2	C3	C4	C5	C6	C7
A1	0.042801	0.085048	0.100811	0.125242	0.124278	0.060455	0.096346
A2	0.142265	0.070188	0.052094	0.07836	0.113248	0.143289	0.091475
A3	0.129387	0.056879	0.100811	0.125242	0.143783	0.118042	0.103077
A4	0.118167	0.153431	0.093897	0.052841	0.036267	0.128465	0.091152

A5	0.110531	0.095456	0.116893	0.064669	0.091668	0.062861	0.149451
A6	0.078094	0.116334	0.07091	0.121166	0.088952	0.112133	0.101485
A7	0.052662	0.102786	0.081601	0.105772	0.096033	0.118179	0.072144
A8	0.022296	0.094112	0.127993	0.09801	0.108546	0.10835	0.079268
A9	0.15601	0.089835	0.145651	0.150337	0.138705	0.122631	0.088909
A10	0.147786	0.135931	0.109339	0.07836	0.058521	0.025596	0.126693

We compute the weighted normalized decision matrix as shown in table 3.

Table 3. The weighted normalized decision matrix.

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**
A1	0.006405	0.011687	0.015251	0.01868	0.016737	0.007881	0.014206
A2	0.021291	0.009645	0.007881	0.011687	0.015251	0.01868	0.013487
A3	0.019364	0.007816	0.015251	0.01868	0.019364	0.015389	0.015198
A4	0.017685	0.021085	0.014206	0.007881	0.004884	0.016747	0.01344
A5	0.016542	0.013118	0.017685	0.009645	0.012345	0.008195	0.022035
A6	0.011687	0.015987	0.010728	0.018072	0.011979	0.014618	0.014963
A7	0.007881	0.014125	0.012345	0.015776	0.012933	0.015406	0.010637
A8	0.003337	0.012933	0.019364	0.014618	0.014618	0.014125	0.011687
A9	0.023348	0.012345	0.022035	0.022423	0.01868	0.015987	0.013109
A10	0.022117	0.01868	0.016542	0.011687	0.007881	0.003337	0.01868

Then we compute the optimality function using Eq. (7). Then we compute the utility degree using Eq. (8)

The utility degree is computed as follows:

$$U_i = \frac{E_i}{V_o} \tag{8}$$

Where V_o is a optimality value of E_i

3.5 Rank of alternatives.

Table 4. The rank of alternatives.

	Optimality function	**Utility degree**	**Rank of alternatives**
A1	0.090848	0.710155	3
A2	0.097924	0.765467	5
A3	0.111062	0.868166	9
A4	0.095927	0.74986	4

A$_5$	0.099565	0.778297	8
A$_6$	0.098035	0.766335	6
A$_7$	0.089104	0.696522	1
A$_8$	0.090683	0.708862	2
A$_9$	0.127927	1	10
A$_{10}$	0.098925	0.773288	7

4. Comparative Analysis

The ninth system was the highest score and the best alternative in Evaluation of Mechanical and Electrical Systems in Public Buildings procedure described above. The third system came in second, while the seventh system came in last. This section conducts a brief comparative analysis with current MCDM techniques, such as the TOPSIS method, VIKOR method, EDAS method, and MABAC method in a plithogenic set environment to confirm the superiority of the suggested model in Evaluation of Mechanical and Electrical Systems in Public Buildings and to further examine the variations in the scoring outcomes of different systems.

Figure 2 shows the rank of the proposed method compared with the other MCDM methods. We show the alternative 9 is the best in all MCDM methods and alternative 7 is the lowest in all MCDM methods. We show our model is strong compared with other MCDM methods.

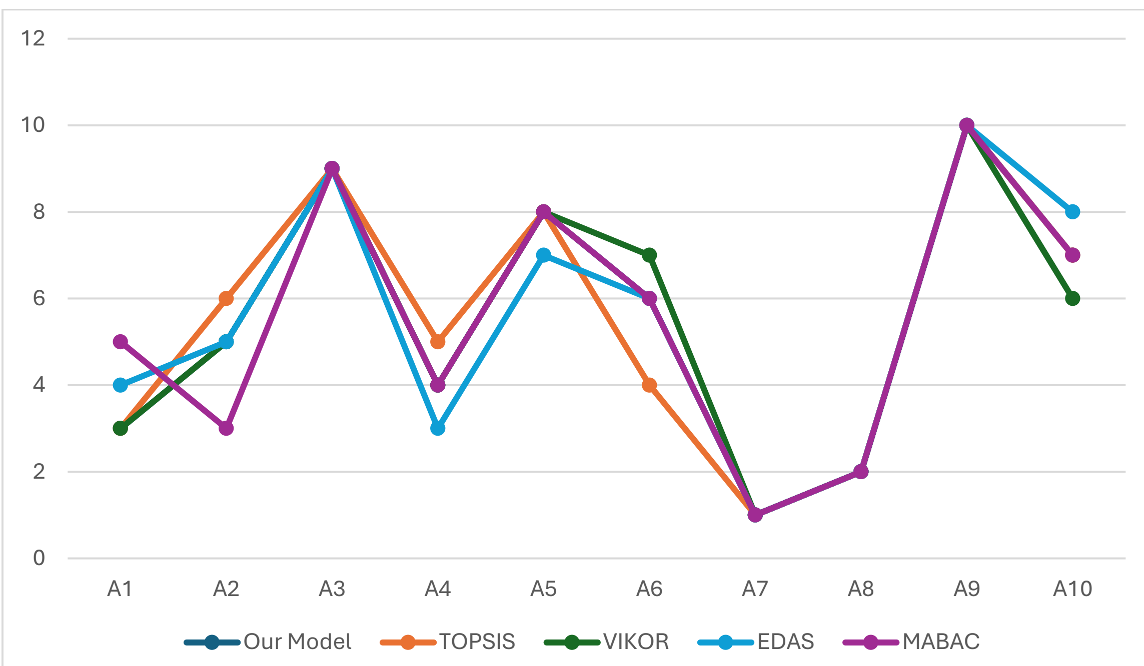

Figure 2. Comparative analysis.

We compute the correlation between our model and other MCDM methods to show the relationship between our model and other MCDM methods. We show the highest correlation between our model and other MCDM methods.

Table 4. The correlation between our model and other MCDM methods.

	Our Model	TOPSIS	VIKOR	EDAS	MABAC
Our Model	-	0.963636	0.987879	0.975758	0.951515
TOPSIS	0.963636	-	0.927273	0.927273	0.890909
VIKOR	0.987879	0.927273	-	0.951515	0.939394
EDAS	0.975758	0.927273	0.951515	-	0.951515
MABAC	0.951515	0.890909	0.939394	0.951515	-

5. Conclusions

This study proposed an MCDM method for evaluation of Mechanical and Electrical systems in public Buildings. This evaluation contains uncertainty and vague information. So, we proposed an ARAS method to rank the alternatives and compute the criteria weights. Three experts are invited to evaluate the criteria and alternatives. The ARAS method is integrated with the plithogenic sets to deal with uncertainty data. Then we combine plithogenic numbers into single matrix. Then we obtained crisp values. Then we obtained the criteria weights. The proposed method is applied into seven criteria and ten alternatives. The results show the 9 is the best and alternative 7 is the worst. We compared the proposed methodology with other MCDM methods. The results show the alternative 9 is the best in all MCDM methods. The results indicate the proposed methodology is strong compared with other MCDM methods.

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