



A Fusion Selection Approach of the Best Plan for Energy Remodeling Hospital Wards Using a Multi-Criteria Decision-Making

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Abstract

Energy policy implementation relies heavily on assessing savings from retrofitting for energy efficiency. Because of their unique purpose, hospitals need energy-efficient renovations to improve indoor air quality and create a pleasant space for staff and visitors. Because of this crucial distinction, investors' preferences must be considered when deciding on refurbishment plans. Considering elements including energy savings, financial viability, and thermal comfort, this research provides a multi-criteria decision-making (MCDM) approach to guide investors in choosing the most effective remodeling plan for hospital wards. We used the MABAC method as an MCDM fusion method to combine the various criteria and alternatives to select the best one. We used ten criteria and ten alternatives in this study. We compute the weights of criteria to rank the criteria. Then, we used the MABAC fusion to rank the alternatives. The results show the financial viability has the least weight and the building envelope has the highest. We conducted a sensitivity analysis to show the stability of the results in this study.

Keywords: MCDM Fusion; MABAC Fusion; Energy; Hospital Wards; Remodeling

1. Introduction

Renovating to reduce energy use is a major factor in the building industry's push towards more environmentally friendly practices. The most recent survey data shows that hospitals in our nation use as much as 353.5 kWh/m² of energy annually, more than twice as much as the energy utilized by other government-owned structures. Healthcare institutions' energy needs continue to rise despite the widespread use of energy-efficient equipment. People's desire for improved customer service and pleasant surroundings are major motivating factors. And since most hospital structures only last between 50 and 60 years, many of the hospitals in use today are rather old. Thus, improving hospitals' overall performance is crucial to implementing energy-efficient remodeling initiatives. In addition to helping the planet, this will improve the quality of the space in which doctors and patients work[1]–[3].

Because of their high energy use, hospitals have a great deal of room for improvement in terms of energy efficiency. Research on methods of decreasing hospitals' energy use via energy-efficient renovations has gained traction in recent years. The retrofit measures for four hospital buildings were analyzed by Buonomano et al. using a dynamic performance simulation. The findings revealed that energy savings of 19.0% to 20.2% may be achieved by concurrently installing radiator systems, thermostatic valves, and AHU (Air Handling Unit) control systems[4], [5].

Analysis and assessment provide decision-makers with a thorough grasp of the benefits and drawbacks of energy-efficient refurbishment plans. They may then choose the best option and determine which energy-saving strategies will have the most impact. Cost-benefit analysis, multi-criteria decision-making, and multi-objective optimization are just some of the assessment methodologies that have been studied by several academics and used to build energy retrofit programs [3], [6].

Decision-making is a mentally complicated process that involves weighing several factors in order to arrive at a desired outcome. In addition to being impacted by physiological, biological, cultural, social, etc. aspects, this process may also be rational or illogical and make use of implicit or explicit assumptions. These factors, together with those of authority and risk, may increase or decrease the complexity of a decision's implementation. These days, we can automatically calculate and estimate the answers to even the most complicated decision-making issues because of the widespread availability of mathematical equations, vast statistical data, mathematics, economic theory, and computing technologies[7], [8][9].

One of the most precise approaches to decision-making, MCDM fusion or multi-criteria decision analysis (MCDA) may be thought of as a revolution in the area. Benjamin Franklin's exploration of the moral algebra notion is one of the first scientific projects on multi-criteria decision-making[10], [11]. Since the 1950s, a number of empirical and theoretical scientists have worked on MCDM fusion techniques to investigate their mathematical modeling potential, with the goal of developing a framework that can aid in the organization of decision-making issues and the generation of preferences from among available options. MCDM fusion encompasses a wide variety of approaches, each of which has its own unique characteristics[12]–[14].

In order to determine the optimal answer, this strategy takes into account a wide range of qualitative and quantitative factors. Many decision-making issues, for instance, often include factors such as cost or price and quality of the procedures. In addition, the relevance of each criterion in a given situation leads to the expert groups assigning various weights to the criteria[15]–[17][18].

MCDM fusion may be used to common issues that people face[19]–[21]. The assessment of criteria remains a key issue, especially when the problem is centered on more crucial topics like capital levels. Decisions in such cases must be grounded on thorough planning and a clear assessment of all relevant factors utilizing suitable software and hardware. When several criteria must be considered in order to arrive at an optimal solution that satisfies all decision-makers, MCDM fusion is put to use in the practical realm[22]–[24][25].

2. Methodology Fusion

This section introduces a MCDM fusion methodology by combing the criteria and alternative in energy remodeling hospital rewards. We used the MABAC fusion method to rank the alternatives. In 2015, Pamucar and Cirovic presented the Multi-Attributive Border Approximation Area Comparison (MABAC) technique. The starting point for this technique is to establish how far each option is from the region of approximation around the borders. In fact, the gap among the distances is used to rate and rate each possible choice. This strategy is often used in certain locales[26]–[29]. Figure 1 shows the steps of the MABAC fusion method.



Figure 1: The steps of MABAC MCDM fusion.

Step 1. Build the decision matrix

The input of the MABAC fusion method is a decision matrix. The decision matrix is built based on a set of criteria and alternatives. The experts rate the criteria and alternatives by using a scale from 1 to 9.

$$D = \begin{bmatrix} d_{11} & \dots & d_{1n} \\ \vdots & \ddots & \vdots \\ d_{m1} & \dots & d_{mn} \end{bmatrix} \tag{1}$$

Where $i = 1, 2, \dots, m; j = 1, 2, \dots, n$

Step 2. Normalize the decision matrix

The decision matrix is normalized based on the positive and negative criteria as:

$$R_{ij}^* = \frac{d_{ij} - d_i^-}{d_i^+ - d_i^-} \tag{2}$$

$$R_{ij}^* = \frac{d_{ij} - d_i^+}{d_i^- - d_i^+} \tag{3}$$

Where $\begin{cases} d_i^- = \min(d_1, d_2, \dots, d_m) \\ d_i^+ = \max(d_1, d_2, \dots, d_m) \end{cases}$

Step 3. Compute the weighted normalized decision matrix

The weights of the criteria are computed by using the average method. Then the weights of criteria are used to compute the weighted normalized decision matrix based on the normalized decision matrix values:

$$wr_i = w_j + R_{ij}^* w_j \tag{4}$$

Step 4. Compute the border approximation area.

$$g_j = (\prod_{i=1}^m wr_i)^{\frac{1}{m}} \tag{5}$$

Step 5. Compute the distance from the border approximation area.

$$u_{ij} = wr_i - g_j \tag{6}$$

Step 6. Compute the total distance

$$T_i = \sum_{j=1}^n (u_{ij}) \quad (7)$$

Step 7. Rank the alternatives

The alternatives are ranked based on the largest value of T_i .

3. Results

In this section, we introduce the results of the MABAC fusion MCDM methodology. We used the fusion approach to combine the various criteria and alternatives to compute the weights of criteria and rank the alternatives. We select the best remodeling strategy for hospital wards. We collect the ten criteria and ten alternatives in this study. We described the criteria and alternatives in this study as:

- C1. Building Codes and Conditions: Complying with appropriate building regulations and energy efficiency requirements is a basic factor for energy-efficient refurbishment.
- C2. Life Cycle Assessment: The environmental effects of building renovations may be measured with the use of a life cycle assessment (LCA).
- C3. Water Efficiency: The total energy efficiency of a remodeling project may be improved by including water efficiency metrics as the criterion.
- C4. Air Quality: Criteria for an energy-efficient remodel should include those that provide a healthy indoor environment.
- C5. Lighting: One of the criteria for an energy-efficient remodel is the installation of new, more efficient lighting.
- C6. Building Envelope: One of the most important criteria for an energy-efficient renovation is the enhancement of the building envelope, which consists of the walls, roof, windows, and doors.
- C7. Renewable Energy Integration: One factor that may improve the energy efficiency of refurbished buildings is the use of renewable energy technology.
- C8. Financial Viability: The cost-effectiveness of an energy-efficient remodel is one indicator of a project's viability.
- C9. HVAC Systems: One of the most significant ways to improve a building's energy efficiency is via HVAC system upgrades or replacements.
- C10. Energy Management and Control: A critical aspect of green refurbishment is the installation of cutting-edge energy management and control technologies.

The alternatives in this study are described as:

- A1. Renewable Energy Integration: Putting solar photovoltaic (PV) panels on the roof or in neighboring fields to produce renewable energy for use inside the building's internal grid.
- A2. Water efficiency measures: Upgrading plumbing fixtures to low-flow or water-saving alternatives, such as low-flow showerheads and faucets.
- A3. Building Envelope Enhancements: Reducing draughts and heat loss by sealing air leaks and increasing airtightness of the building envelope.
- A4. Window and Door Replacement: Putting in low-emissivity (Low-E) coatings and double or triple glass on windows and doors reduces heat loss and gain by a significant amount.
- A5. HVAC systems improvements: Putting in more energy-efficient HVAC (heating, ventilation, air conditioning) units.
- A6. Energy-Efficient Appliances and Equipment: Substituting old appliances with Energy Star-certified models is one way to cut down on your home's energy use.
- A7. Insulation Upgrades: Adding or upgrading insulation in roofs, walls, and floors to limit heat transmission and increase thermal efficiency.
- A8. Occupant Behavior and Awareness: Teaching tenants how to reduce energy use by changing their behavior in relation to the building's lighting, heating and cooling systems, and other appliances.
- A9. Energy Management Systems: Using cutting-edge BAS and energy management technologies to keep tabs on and regulate energy use.
- A10. Lighting Retrofits: Installation of energy-saving lighting options like LED (light-emitting diode) bulbs.

Step 1. Eq. (1) is used to build the decision matrix between ten criteria and ten alternatives to be an input of MABAC fusion. The experts evaluate the criteria and alternatives by using a scale from 1 to 9.

Step 2. Then we normalize the decision matrix by using Eqs. (2 and 3) for positive and negative criteria. All criteria are positive except the financial criterion is negative. Table 1 shows the normalization decision matrix.

Table 1: The normalization decision matrix by the MABAC fusion method.

	HAC ₁	HAC ₂	HAC ₃	HAC ₄	HAC ₅	HAC ₆	HAC ₇	HAC ₈	HAC ₉	HAC ₁₀
HAA ₁	0	0.25	0	0.25	0.85714	1	0.71428	0.375	0.5	0.57142
HAA ₂	0.125	0.125	0.85714	0.75	0.57142	0.33333333	0.42857	0	0.875	0.42857
HAA ₃	0.5	0.5	0	0.125	0.14285	1	0.71428	0	1	0
HAA ₄	0.625	0.625	0.14285	0.5	1	0.5	0.57142	0.125	0.625	0.71428
HAA ₅	1	0.25	0.57142	1	0	0.5	0.42857	1	0.5	0.85714
HAA ₆	0.5	1	1	0.25	0.14285	0.33333333	0	0.875	0.25	1
HAA ₇	0.875	0.875	0.85714	0.625	0.85714	1	1	0.75	0.125	0.57142
HAA ₈	0.75	0.625	0.71428	0	0	0	0.57142	0.625	0	0.42857
HAA ₉	0.375	0.25	0	0.5	0.57142	1	1	0.75	0.375	0
HAA ₁₀	0.5	0	0.42857	0.625	1	0.83333333	0.85714	0.375	0.5	0

Step 3. Then we compute the weights of the criteria by the average method as shown in Figure 2. The results of the weights of criteria show that financial viability is the least weight and the building envelope is the highest weight in all criteria.

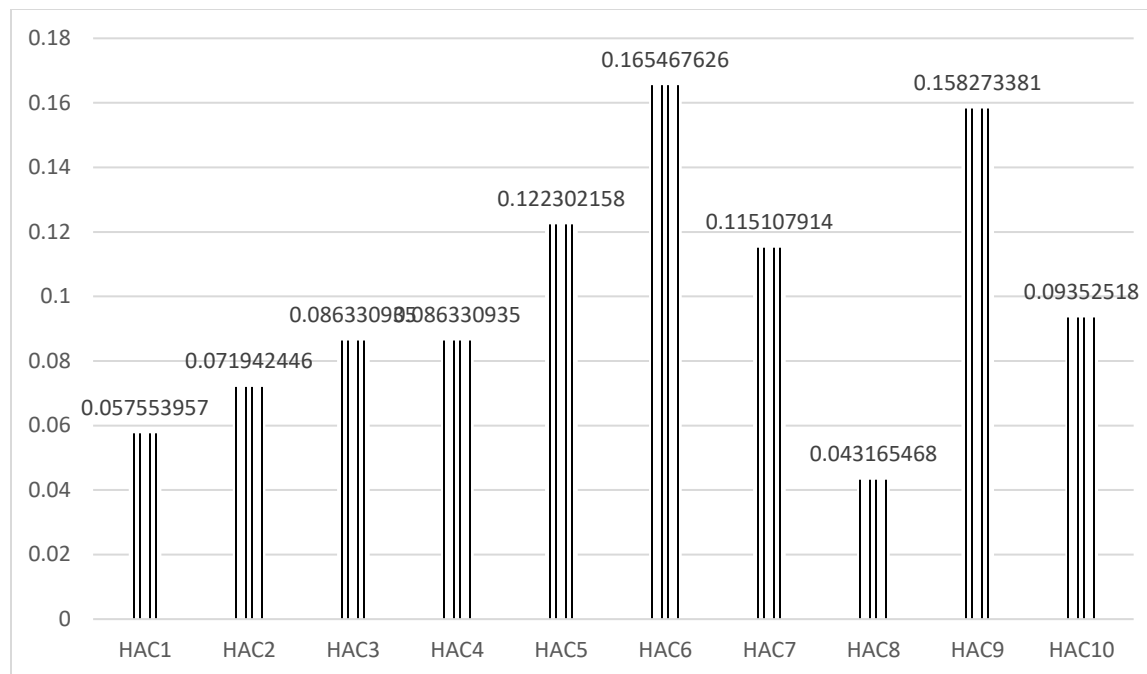


Figure 2: The weights of ten factors.

Then we multiply the weights of criteria by the normalization decision matrix to obtain the weighted normalized decision matrix by using Eq. (4) as shown in Table 2.

Table 2: The weighted normalized decision matrix by the MABAC fusion method.

	HAC ₁	HAC ₂	HAC ₃	HAC ₄	HAC ₅	HAC ₆	HAC ₇	HAC ₈	HAC ₉	HAC ₁₀
HAA ₁	0.0575 54	0.0899 28	0.0863 31	0.1079 14	0.2271 33	0.3309352 52	0.1973 28	0.0593 53	0.2374 1	0.1469 68
HAA ₂	0.0647 48	0.0809 35	0.1603 29	0.1510 79	0.1921 89	0.2206235 01	0.1644 4	0.0431 65	0.2967 63	0.1336 07
HAA ₃	0.0863 31	0.1079 14	0.0863 31	0.0971 22	0.1397 74	0.3309352 52	0.1973 28	0.0431 65	0.3165 47	0.0935 25
HAA ₄	0.0935 25	0.1169 06	0.0986 64	0.1294 96	0.2446 04	0.2482014 39	0.1808 84	0.0485 61	0.2571 94	0.1603 29
HAA ₅	0.1151 08	0.0899 28	0.1356 63	0.1726 62	0.1223 02	0.2482014 39	0.1644 4	0.0863 31	0.2374 1	0.1736 9
HAA ₆	0.0863 31	0.1438 85	0.1726 62	0.1079 14	0.1397 74	0.2206235 01	0.1151 08	0.0809 35	0.1978 42	0.1870 5
HAA ₇	0.1079 14	0.1348 92	0.1603 29	0.1402 88	0.2271 33	0.3309352 52	0.2302 16	0.0755 4	0.1780 58	0.1469 68
HAA ₈	0.1007 19	0.1169 06	0.1479 96	0.0863 31	0.1223 02	0.1654676 26	0.1808 84	0.0701 44	0.1582 73	0.1336 07
HAA ₉	0.0791 37	0.0899 28	0.0863 31	0.1294 96	0.1921 89	0.3309352 52	0.2302 16	0.0755 4	0.2176 26	0.0935 25
HAA ₁₀	0.0863 31	0.0719 42	0.1233 3	0.1402 88	0.2446 04	0.3033573 14	0.2137 72	0.0593 53	0.2374 1	0.0935 25

Step 4. Eq. (5) is used to compute the border approximation area.

Step 5. Eq. (6) is used to compute the distance from the border approximation area as shown in Table 3.

Table 3. The distance between alternatives and border approximation area by the MABAC fusion method.

	HAC ₁	HAC ₂	HAC ₃	HAC ₄	HAC ₅	HAC ₆	HAC ₇	HAC ₈	HAC ₉	HAC ₁₀
HAA₁	-	-	-	-	-	-	-	-	-	-
	0.9294	0.9143	0.9368	0.9156	0.8364	0.7747199	0.8675	0.8973	0.8510	0.8844
	9	1	8	8	3	1	3	1	7	7
HAA₂	-	-	-	-	-	-	-	-	-	-
	0.9222	0.9233	0.8628	0.8725	0.8713	0.8850316	0.9004	0.9135	0.7917	0.8978
	9		9	1	8	6	2		2	3
HAA₃	-	-	-	-	-	-	-	-	-	-
	0.9007	0.8963	0.9368	0.9264	0.9237	0.7747199	0.8675	0.9135	0.7719	0.9379
	1	2	8	7	9	1	3		3	1
HAA₄	-	-	-	-	-	-	-	-	-	-
	0.8935	0.8873	0.9245	0.8940	0.8189	0.8574537	0.8839	0.9081	0.8312	0.8711
	1	3	5	9	6	2	7		8	1
HAA₅	-	-	-	-	-	-	-	-	-	-
	0.8719	0.9143	0.8875	0.8509	0.9412	0.8574537	0.9004	0.8703	0.8510	0.8577
	3	1	5	3	6	2	2	3	7	5
HAA₆	-	-	-	-	-	-	-	-	-	-
	0.9007	0.8603	0.8505	0.9156	0.9237	0.8850316	0.9497	0.8757	0.8906	0.8443
	1	5	5	8	9	6	5	3	4	9
HAA₇	-	-	-	-	-	-	-	-	-	-
	0.8791	0.8693	0.8628	0.8833	0.8364	0.7747199	0.8346	0.8811	0.9104	0.8844
	3	4	9		3	1	4	2	2	7
HAA₈	-	-	-	-	-	-	-	-	-	-
	0.8863	0.8873	0.8752	0.9372	0.9412	0.9401875	0.8839	0.8865	0.9302	0.8978
	2	3	2	6	6	4	7	2	1	3
HAA₉	-	-	-	-	-	-	-	-	-	-
	0.9079	0.9143	0.9368	0.8940	0.8713	0.7747199	0.8346	0.8811	0.8708	0.9379
		1	8	9	8	1	4	2	5	1
HAA₁₀	-	-	-	-	-	-	-	-	-	-
	0.9007	0.9322	0.8998	0.8833	0.8189	0.8022978	0.8510	0.8973	0.8510	0.9379
	1	9	8		6	5	8	1	7	1

Step 6. Eq. (7) is used to compute the total distance.

Step 7. Then the alternatives are ranked based on the maximum value in total distance as shown in Figure 3. We show that alternative 7 is the best and alternative 8 is the worst.

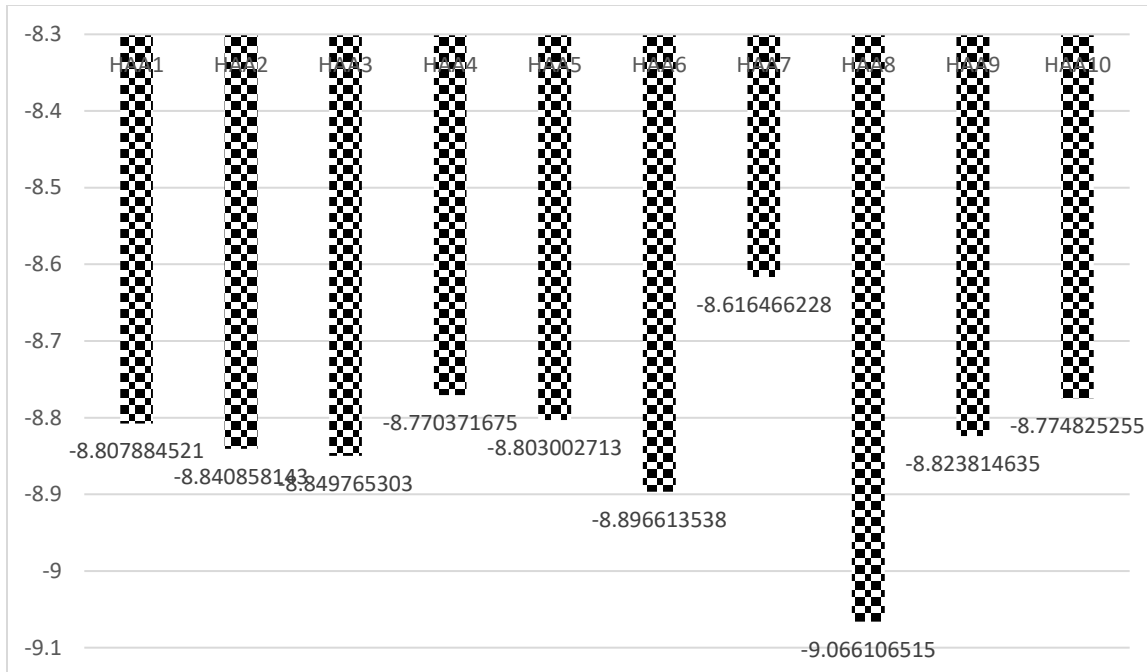


Figure 3: The total distance between alternatives.

We applied the sensitivity analysis in this paper to show the strength of the proposed MCDM fusion method and the stability of the results. We suggested ten cases in weights of criteria. In the first case, we put one criterion 0.15 weight, and other criteria are equal as shown in Figure 4.

Then we use these cases as input into a MABAC fusion method. We show the rank of alternatives. The alternative 7 is the best alternative in all cases and the alternative 8 is the worst in all alternatives. So the results of this model are stable.

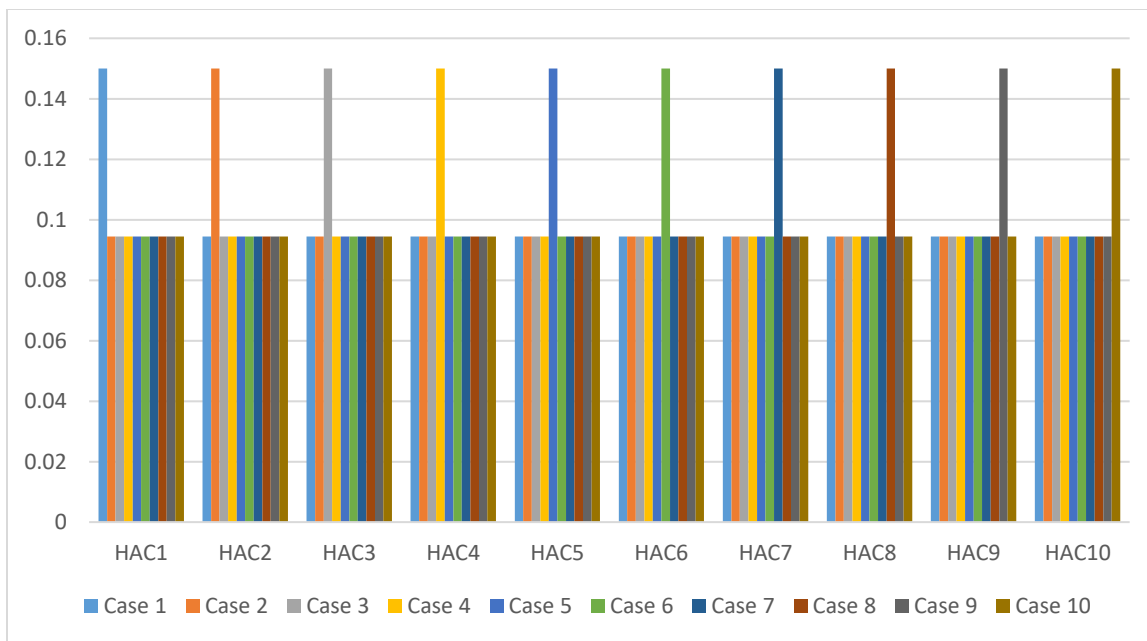


Figure 4: The ten cases in weights of criteria.

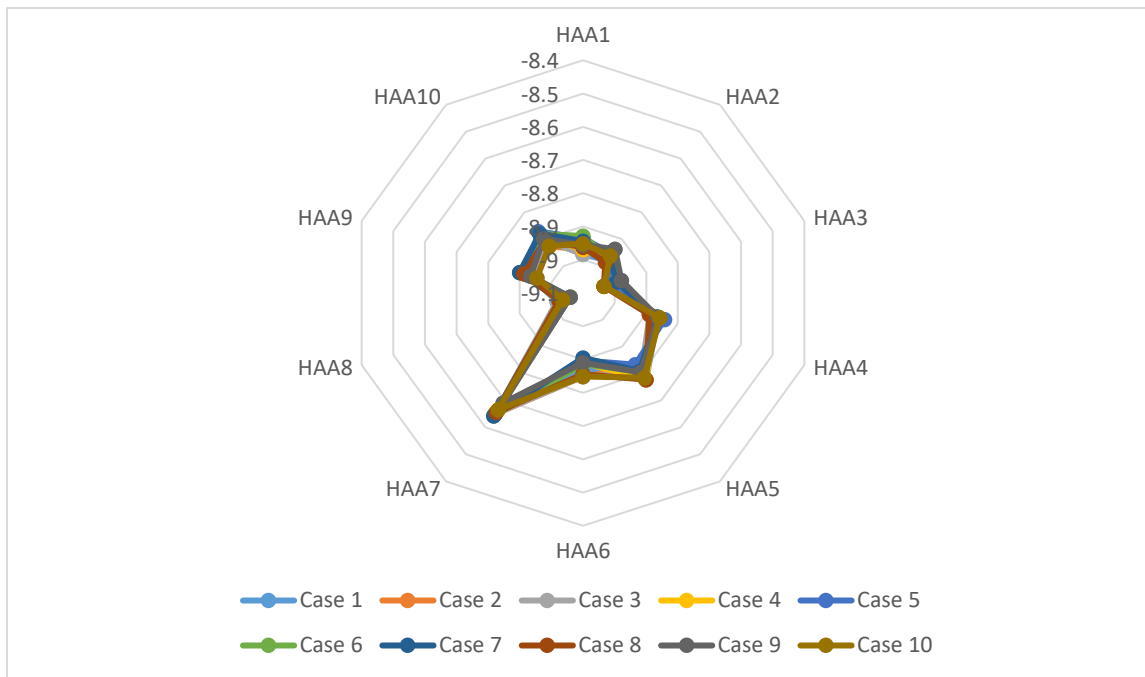


Figure 5: The total distance is under ten cases in weights of criteria.

4. Conclusions

When renovating with energy efficiency in mind, there are many wins for hospitals and the environment. Hospitals can save money, provide better patient care, and help the environment if they prioritize energy efficiency.

Options for making hospital wards more energy efficient include replacing windows and doors, installing energy-efficient lighting, upgrading heating, ventilation, and air conditioning systems, and incorporating renewable energy sources. These methods can potentially cut energy costs drastically, provide more precise temperature regulation, improve air quality within buildings, and foster recovery.

Energy management systems and controls, water efficiency measures, and the use of environmentally friendly building materials all contribute to the overall efficiency of hospital wards regarding energy use. This kind of action assists in lessening the adverse effects on the environment that are often linked with healthcare delivery.

Hospitals may benefit from green building certifications and fulfilling regulatory requirements when implementing energy-efficient remodeling plans in line with the increased emphasis on sustainable healthcare practices. These actions help the local ecosystem, boost the hospital's public profile, and recruit eco-conscious patients and employees.

When planning for energy-efficient renovations, hospital administrators, designers, and facility managers must consider the unique needs of healthcare facilities. Energy efficiency must be balanced with patient comfort, infection control, and the necessity for specialized equipment to prevent disruptions in healthcare delivery.

In conclusion, investing in energy-efficient ward renovations is a wise choice for the long-term viability of hospitals and other healthcare institutions. Hospitals may help patients and the environment by lowering their carbon footprint, increasing their patients' level of comfort, and cutting down on unnecessary energy use.

We collated ten criteria and ten alternatives in this study to select the best remodeling strategy in hospital wards. We used the MABAC as a fusion method to combine various criteria and alternatives to choose the best alternative. We built the decision matrix between criteria and alternatives using the MABC fusion method. Then, we compute the weights of the criteria to rank it. We found that criterion 6 is the best, and criterion 8 has the most miniature weights. Then, we used the criteria weights in an MABAC fusion method to compute the weighted normalized decision matrix between criteria and alternatives. The MABAC fusion shows that alternative 7 is the best and alternative 8 is the worst.

We conducted the sensitivity analysis to show the stability of the results. The results show the rank is stable under different cases in criteria weights.

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