Experimental study of an automotive air conditioning system with alternative refrigerants

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Abstract

Optimizing efficiency studies were carried out to comply with environmental norms by using MCDM techniques to pick low GWP refrigerants for automotive air conditioning. Multi-criteria optimization for time consumption based on ratio analysis plus full multiplicative form (MULTIMOORA), is being employed in this work to compare 10 distinct alternatives with 10 criteria. Thermal conductivity, vapor pressure, saturation fluid density, latent specific heat, fluid viscosity, GWP, ozone-depleting potential, and cost per pound are among the many response qualities suited for data acquisition in terms of thermodynamics, and environmental stewardship, and economics. It is possible to standardize decision-makers grading and weighting systems using MCDM methodologies. RAA3 had the greatest rank among the 10 refrigerants tested in the MULTIMOORA methodology. The EDAS and TOPSIS techniques identified R-744 to be the worst refrigerant, whereas the MOORA approach showed RAA5 to be the worst refrigerant.

Keywords: MCDM; MULTIMOORA; refrigerants; air automobile; efficiency; Optimization

1. Introduction

There is a great deal of concern about the carbon dioxide emissions from the use of high climate change refrigerant R134a in automotive air conditioners (AAC) systems[1], [2]. Climate change potential (GWP) is limited to 150 [3] as per European Union rules. Along with this, other important features, including thermophysical, flowability, toxicity, and quality requirements, play an important part in the selection of novel refrigerants [4]. When it comes to modeling refrigeration operations, the materials and shape of the AAC system, as well as its refrigerant properties, have a significant role[5]. Temperature-dependent factors play an important influence in the choosing of a refrigerant. Due to their high production costs, several refrigerants that are suitable for AAC applications have not been used. Refrigerant candidates should have the required thermodynamic parameters to provide the best possible COP, such as increased heat of fusion, heat capacity (TC), and specific heat, as well as reduced dynamic viscosity [6]–[9].

Additional considerations include ozone layer possibility (ODP) and global warming potential (GWP) with lower inventory costs in refrigerant choices[10]. Because of these limitations, selecting a refrigerant for precise use becomes more difficult and cumbersome. R1234yf[11]–[14], R1234z (E)[15]–[17], R152a[18]–[20], R290[21], [22], R744[23], [24], R430A[25]–[27], and R444A [28] are prominent AAC replacements for R134a [10]. All these refrigerants have their own set of advantages and disadvantages. It now takes a lot of time and money to create refrigerants that focus on the suggested, modeling, and experimental methodologies. Multi-criteria decision-making

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(MCDM) should be improved so that it can deal with thermodynamic, ecological, and economic aspects and yet produce the best possible outcomes.

Here, research on the optimization of several thermal, photovoltaic, and industrial applications utilizing distinct MCDM tools is summarised and presented. The best heat-transfer fluids (HTFs) for photovoltaic collectors were chosen by Kumar et al. [29]using TOPSIS and grey relational analysis the best heat-transfer fluids (HTFs) for photovoltaic collectors were chosen by Kumar et al. [29]using TOPSIS and grey structural analysis of water were chosen as the best working fluid for powering solar systems from among the 16 options considered. An ideal glazier material using the TOPSIS technique and seven sun thermal application choices was used in the study by Kumar et al.[30][31]. When faced with the provided input factors and seven different materials, they decided on polysulfone glazing (connectedness coefficient score = 0.628) as a viable solution. Electrical discharge machining was used to execute a Taguchi orthogonal experimentation on a cryogenically chilled electrode, and GRA was used to enhance the processing factors, such as the gap voltages, currents, and pulse-on times.

Using the grey relation grade (GRG) as a processing element was determined to be the most effective. There was a maximum GRG of 0.0775. Zhou et al. [32]used a non-structural fuzzy judgment approach to pick the best-condensed heat exchangers (HEXs). Plate HEXs & plate-fi HEXs are only viable if their visual characteristics are taken into account, according to their findings. Using orthogonal arrays and a grey-based fuzzy method, Chou et al. [33]improved the parallel-plain fi heat sink's design parameters. A four-level factorial design with L16-based central composite design CCD and fie characteristics were used in this investigation. Numerous heat transfer performance parameters are significantly improved by using these methods in verification tests using optimal settings for various design aspects.

As a novel instrument for the evaluation of trench building sustainability, Casanovas-Rubio et al. [34] developed the Sustainability Index for Trenches (SIT). Sensitivity testing proved to be successful, with findings revealing slight variances ranging from zero percent to 18.4 percent, suggesting significant improvements in the weight allocation under different circumstances.

The weighting of the various criteria is also an essential part of the MCDM analysis. Weights are numerical numbers between 0 and 1 that represent the relative relevance of a factor in multi-criteria issues. EWM, an entropy weight technique (EWM), is used to assess the weight of each criterion[35]–[37]. The linguistic entropy weight approach and the fuzzy axiomatic design were combined by Feng et al. [38]to provide an integrated MCDM technique for selecting a good site for an electric vehicle (EV) charging station. Their findings reveal that the advantages of LEW and fuzzy axiomatic design (FAD) techniques in the selection of EV charging station locations are persistent. Analyzing waste removal options, Kahraman et al. [39]proposed an EDAS method; Stanujic et al. [40] adapted the EDAS technique for use with grey numbers.

There are four parts to this research: The steps of MULTIMOORA application evaluations are presented in Section 2. Section 3 presented the application and results. Section 4 outlines the conclusion and future work.

2. Multi-criteria optimization based on ratio analysis plus full multiplicative form (MULTIMOORA)

Retrofitting/selecting new refrigerant, thermophysical attributes had a significant effect in determining the efficiency properties of particular components as well as entire systems, including cooling capacity and COP. Many thermophysical parameters affect the AAC system's performance, including vapor pressure, vapor densitometer, liquid density and viscosity, vapor flowability, and enthalpy of evaporation of water. When making the switch to a different refrigerant, consider the safe working environment for people more than the system. The most important considerations in refrigerant choice are things like flammability, cytotoxicity, suffocation, and physical risks. Safety standard 34 categorized the refrigerants by their flammability and toxicity properties Proposed system, safe system of work, and other procedures for diverse AAC systems may be handled according to these aspects. This is important. As a final incentive for system makers and the general public, the cost of the new refrigerant should serve to encourage its use. The thermodynamic characteristics, environmental circumstances (GWP, flammability, and toxicity), and financial concerns all play a role in selecting the optimal refrigerant.

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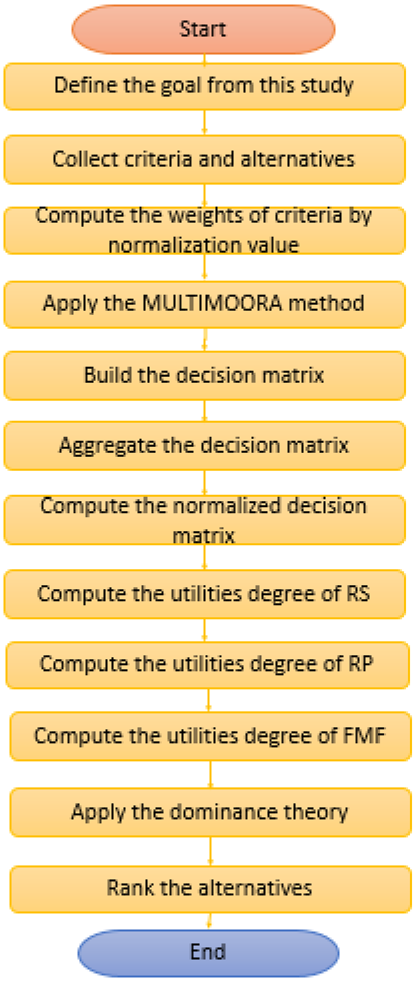

Figure 1: The steps of this work.

According to Brauers and Zavadskas [41], MULTIMOORA is one of the most successful multi-criteria decision-making systems available[42]. For this purpose, we use three lower-level methods: ratio system (RS), reference point ("RP"), and full multiplication form ("FMF"). The dominance hypothesis is used to establish the ultimate rankings of alternatives. Figure 1 shows the steps of this work. A decision issue's generic evaluation matrices are stated as

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \qquad (1)$$

Where $i = 1,2,3 \dots . m; j = 1,2,3, \dots n$

Step 1: Normalize the decision matrix

$$x_{ij}^{*} = \frac{x_{ij}}{\sum_{i=1}^{m} (x_{ij})^2} \qquad (2)$$

Step 2: RS is used to compute the utility value as

$$u_1(a_i) = \sum_{j=1}^{H} x_{ij}^{*} - \sum_{j=H+1}^{N} x_{ij}^{*} \qquad (3)$$

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The number of positive criteria is denoted by the H and the number of cost criteria is denoted by the N-H.

Step 2.1: Rank the alternatives based on the highest value of the RS

$$R_1 = \{r_1(a_1), r_1(a_2), \ldots, r_1(a_m)\} \quad (4)$$

Step 3: RP is used to compute the utility value as

$$u_2(a_i) = \max_j\{d(r_j^*, x_{ij}^*)\} \quad (5)$$

Where the $d(r_j^*, x_{ij}^*)$ is the distance between r_j^* and x_{ij}^*

$$r_j^* = \left\{\max_i x_{ij}^*, j \leq H; \min_i x_{ij}^*, j > H;\right\} \quad (6)$$

Where r_j^* refers to the reference point.

Step 3.1: Rank the alternatives based on the lowest value of $u_2(a_i)$

$$R_2 = \{r_2(a_1), r_2(a_2), \ldots, r_2(a_m)\} \quad (7)$$

Step 4: FMF is used to compute the utility value as

$$u_3(a_i) = \frac{\prod_{j=1}^{H} x_{ij}^*}{\prod_{j=H+1}^{N} x_{ij}^*} \quad (8)$$

Step 4.1: Rank alternatives based on the highest value of $u_3(a_i)$

$$R_2 = \{r_3(a_1), r_3(a_2), \ldots, r_3(a_m)\} \quad (9)$$

Step 5: Obtain the final rank of alternatives by using the dominance theory that combined the three ranks into one rank.

$$R_i (i = 1,2,3) \quad (10)$$

3. Results and Analysis

The 10 refrigerants and 10 criteria mentioned in figure 2 were evaluated utilizing the multi-criteria decision-making systems MULTIMOORA method in this research to find the best refrigerant for AAC applications. The MULTIMOORA analyses' normalized matrix values for different refrigerants were computed.

Figure 2 depicts the first phase of this investigation, which is to pick the proper refrigerant. DM1 is the lead group, followed by DM2 and DM3, which are each comprised of three experts. In this research, the experts are the ones making the final decisions. Experts in this field have a wide range of information and expertise to draw upon.

Three experts evaluated the criteria and aggregated their opinions. Then compute the normalized values to compute the weights of the criteria as figure 3.

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Figure 2: The criteria of this work

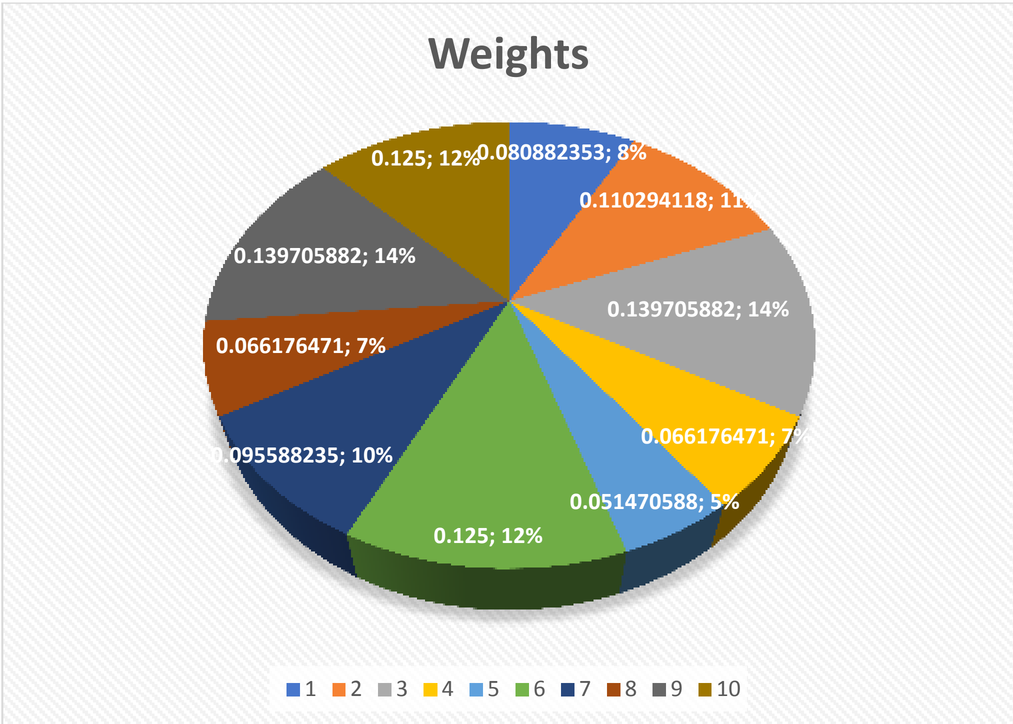

Figure 3: The weights of criteria.

Let three experts evaluate and build the decision matrix between criteria and alternatives using Eq. (1). Then aggregate their opinions to obtain one decision matrix. By using Eq. (2) the normalization decision matrix is computed as in table 1. According to Eq. (3), the utility of the RS is computed as shown in table 2. Then compute the utility degree of RF by using Eq. (5) as shown in table 3. Then compute the utility of FMF by using Eq. (8). Then obtain the rank of three approaches as shown in figure 4. Then apply the dominance theory to combine the rank as shown in figure 5. RAA3 is the best alternative and RAA5 is the worst alternative.

Table 1: The normalization decision matrix

	RAC1	RAC2	RAC3	RAC4	RAC5	RAC6	RAC7	RAC8	RAC9	RAC10
RAA1	0.024	0.035	0.018	0.025	0.018	0.020	0.022	0.023	0.022	0.018
RAA2	0.024	0.023	0.024	0.019	0.021	0.017	0.019	0.023	0.016	0.027
RAA3	0.021	0.027	0.024	0.022	0.015	0.033	0.025	0.023	0.022	0.027
RAA4	0.017	0.014	0.031	0.005	0.028	0.020	0.019	0.019	0.019	0.024
RAA5	0.021	0.027	0.018	0.015	0.028	0.011	0.019	0.012	0.027	0.018
RAA6	0.021	0.023	0.018	0.022	0.018	0.020	0.019	0.019	0.019	0.021
RAA7	0.021	0.031	0.021	0.022	0.028	0.030	0.025	0.016	0.025	0.024
RAA8	0.017	0.023	0.021	0.022	0.018	0.014	0.025	0.034	0.016	0.018
RAA9	0.030	0.018	0.018	0.035	0.021	0.014	0.032	0.030	0.019	0.014

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RAA10	0.021	0.023	0.024	0.025	0.021	0.026	0.015	0.023	0.022	0.024

Table 2: The utility degree of the RS

	RAC1	RAC2	RAC3	RAC4	RAC5	RAC6	RAC7	RAC8	RAC9	RAC10
RAA1	0.002	0.004	0.002	0.002	0.001	0.003	0.002	0.002	0.003	0.002
RAA2	0.002	0.002	0.003	0.001	0.001	0.002	0.002	0.002	0.002	0.003
RAA3	0.002	0.003	0.003	0.001	0.001	0.004	0.002	0.002	0.003	0.003
RAA4	0.001	0.002	0.004	0.000	0.001	0.003	0.002	0.001	0.003	0.003
RAA5	0.002	0.003	0.002	0.001	0.001	0.001	0.002	0.001	0.004	0.002
RAA6	0.002	0.002	0.002	0.001	0.001	0.003	0.002	0.001	0.003	0.003
RAA7	0.002	0.003	0.003	0.001	0.001	0.004	0.002	0.001	0.003	0.003
RAA8	0.001	0.002	0.003	0.001	0.001	0.002	0.002	0.002	0.002	0.002
RAA9	0.002	0.002	0.002	0.002	0.001	0.002	0.003	0.002	0.003	0.002
RAA10	0.002	0.002	0.003	0.002	0.001	0.003	0.001	0.002	0.003	0.003

Table 3: The utility degree of RF.

	RAC1	RAC2	RAC3	RAC4	RAC5	RAC6	RAC7	RAC8	RAC9	RAC10
RAA1	0.001	0.000	0.002	0.001	0.001	0.002	0.001	0.001	0.001	0.001
RAA2	0.001	0.001	0.001	0.001	0.000	0.002	0.001	0.001	0.002	0.000
RAA3	0.001	0.001	0.001	0.001	0.001	0.000	0.001	0.001	0.001	0.000
RAA4	0.001	0.002	0.000	0.002	0.000	0.002	0.001	0.001	0.001	0.000
RAA5	0.001	0.001	0.002	0.001	0.000	0.003	0.001	0.001	0.000	0.001
RAA6	0.001	0.001	0.002	0.001	0.001	0.002	0.001	0.001	0.001	0.001
RAA7	0.001	0.000	0.001	0.001	0.000	0.000	0.001	0.001	0.000	0.000
RAA8	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.000	0.002	0.001
RAA9	0.000	0.002	0.002	0.000	0.000	0.002	0.000	0.000	0.001	0.002
RAA10	0.001	0.001	0.001	0.001	0.000	0.001	0.002	0.001	0.001	0.000

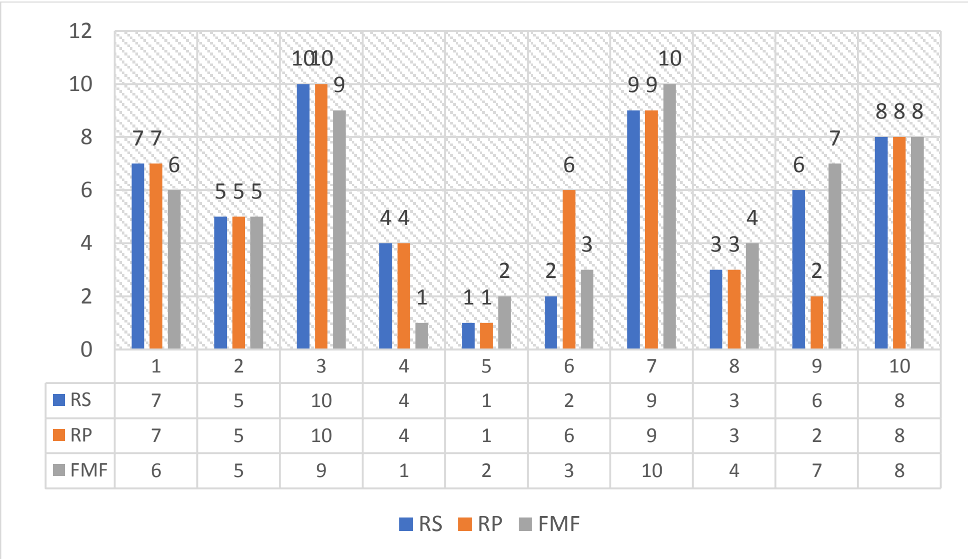

Figure 4: The rank of three approaches.

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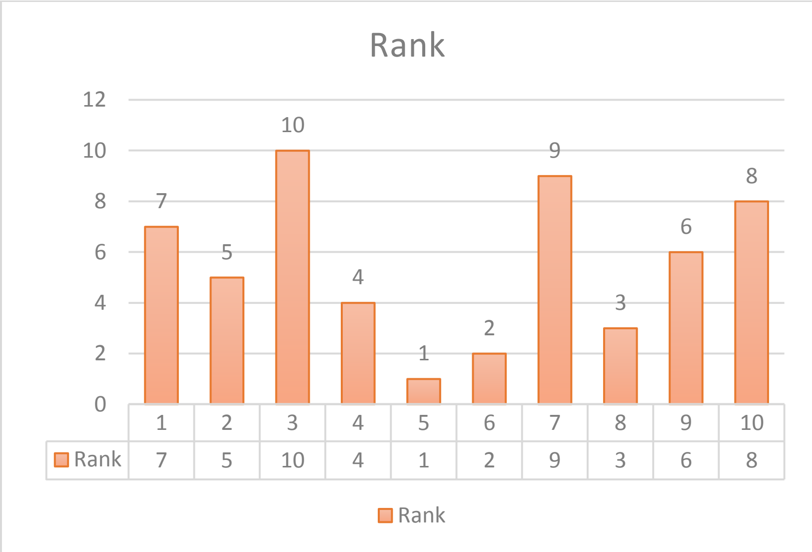

Figure 5: The final rank of alternatives.

4. Conclusion

Because of recent developments in engineering technology, the refrigerant used in AAC systems may be selected with more precision. Depending on the overall goals, such as thermal attributes and social and environmental circumstances, the best refrigerant should be identified and calculated.
Thermal qualities, environmental conditions, and economic considerations are the three most important considerations when evaluating the 10 refrigerant fluids. The best refrigerant fluid was chosen using the MULTIMOORA methods. The MULTIMOORA method is used to rank the alternatives by the three approaches including RS, RP, and FMF.
Agricultural equipment goods, autos, and robots may all be used to test the method's applicability and universality, which can be done in future studies.

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