applied sciences

MDPI

Article

Comparative Analysis of Multi-Criteria Decision-Making Techniques for Outdoor Heat Stress Mitigation

Aiman Mazhar Qureshi and Ahmed Rachid *

Laboratory of Innovative Technologies, University of Picardie Jules Verne, 80000 Amiens, France
* Correspondence: ahmed.rachid@u-picardie.fr

Abstract: Decision making is the process of making choices by organizing relevant information and evaluating alternatives. MCDMs (Multi-Criteria Decision Methods) help to select and prioritize alternatives step by step. These tools can help in many engineering fields where the problem is complex and advanced. However, there are some limitations of the different MCDMs that reduce the reliability of the decision that needs to be improved and highlighted. In this study, Elimination and Choice Expressing Reality (ELECTRE) NI (Net Inferior), NS (Net Superior), Technique for Order Preference by Similarity to Ideal Solutions (TOPSIS), Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE), VIekriterijumsko KOmpromisno Rangiranje (VIKOR), Multi-Objective Optimization Ratio Analysis (MOORA), Weight Sum Method (WSM) and Weighted Product Method (WPM) are applied for the selection of urban heat mitigation measurements under certain criteria. The models were applied using weighting criteria determined by two ways, (i) the direct weighting method and (ii) the Analytic Hierarchy Process (AHP), for precise weighting factoring through pairwise comparison. This numerical research evaluated the reliability of MCDMs using the same decision matrix under different normalization techniques and shows the impact of AHP on the decision. The results show that WSM and PROMETHEE provided reliable and consistent results for all normalization techniques. The combination of AHP with applied MCDMs improved the frequency of consistent ranking, except with ELECTRE-NS.

Keywords: heat stress; multi criteria decision making; analytic hierarchy process; priority; interventions

Citation: Qureshi, A.M.; Rachid, A. Comparative Analysis of Multi-Criteria Decision-Making Techniques for Outdoor Heat Stress Mitigation. *Appl. Sci.* **2022**, *12*, 12308. https://doi.org/10.3390/app122312308

Academic Editor: Maria Vicidomini

Received: 8 August 2022
Accepted: 29 November 2022
Published: 1 December 2022

1. Introduction

Multi-criteria Decision Methods (MCDMs) are valuable tools to handle the selection problem. They are based on five components, which are: goals, thoughts of the specialist, alternatives, criteria, and results. The MCDM requires human recognitions as sources of information where uncertainty and subjective aspects exist. The decision maker's assessments can be expressed by using linguistic terms such as "low importance" or "brilliant performance". The idea of these assessments is often subjective because some criteria that do not have an objective measure, which forces the decision makers to express their thoughts using numeric scales. There are many MCDM methods which are used in different fields of study; for example, the Previously Fuzzy logic method [1] has been applied in the soil sciences [2], supplier's performance [3], for imprecise information related to distribution problems [4], in the field of accounting and finance to develop guidelines for investment decisions [5,6], and in the selection of the appropriate process performance [7]. However, the fuzzy logic method has no potential to measure the level of consistency in the judgments provided by a decision maker.

AHP is a one of the oldest and most trusted decision-making methods [8]. It is a comprehensive technique that has ability to solve the complex decision-making problems by assembling, quantifying, and evaluating the alternative solution through hierarchies [9,10]. Furthermore, it is easy to implement by experts of other fields and overcomes the resulting risk of inconsistency. Consistency plays a vital role in AHP. When the consistency ratio of the pairwise comparison matrix is greater than 10%, it requires a review of the inputs to make the results consistent with the provided judgments [11]. The modified version of Fuzzy-AHP is aimed at removing the vagueness and uncertainty in decision-making, but due to heavy calculations and a high risk of errors, it is difficult to adapt. In contrast, the conventional AHP is quite easy to update, completely reliable, and cost effective, and its analysis can easily be performed by software [12,13]. Previously, the AHP was coupled with other MCDMs, such as MOORA for public transport service quality [14], ELECTRE for personnel selection [15], TOPSIS for the evaluation of knowledge sharing capabilities of supply chain partners [16] and suitable technology transfer strategy for wind turbines [17], PROMETHEE for the selection of policy scenarios for vehicle fleet [18], VIKOR for the assessment of school teachers [19], WSM to evaluate the knowledge in supply chain patterns [20], and WPM for the selection of open-source electronical medical records [21]. In one research, the DEA model was used to assess the performance of small- to medium-sized manufacturing enterprises, and it showed that the MCDM model combined with the AHP was more consistent than stand-alone models where the decision was entirely based on quantitative inputs [22]. The main reason why many companies do not rely on MCDM methods can be due to the fact that decision makers intuitively notice ranking errors [23]. However, there is a need to determine the comparative study on the reliability of the MCDMs. So far, the application of several MCDMs and their comparative study in the field of Urban Heat Stress (UHS) has not been carried out due to long reasoning, which is difficult to quantify and scale. This research is based on the selection of interventions to mitigate outdoor heat stress by using different multicriteria decision applications, such as PROMETHEE, VIKOR, MOORA, ELECTRE (NS, NI), TOPSIS, WPM, and WSM. The applied methods are also combined with AHP, which identifies the effectiveness of standalone application using direct criteria weightage and the impact of AHP on the decision process in field of UHS. The impact of different normalization methods and coherent frequency in ranking results obtained from the application of different MCDMs are also investigated.

The article is organized as follows. Section 2 presents the research background and related work. The underlying concepts and mathematical formulas are given in Section 3. The research methodology is explained in Section 4. Sections 5 and 6 provides the simulation results and discussion. The article ends with a conclusion and some perspectives.

2. Research Background

UHS is the current crucial concern for scientists and residents of medium- and large-sized cities, which are at more risk for heat events. Prolonged exposure can cause heat exhaustion, cramps, stroke, as well as exacerbate pre-existing chronic conditions, such as various respiratory, cerebral, and cardiovascular diseases, especially for vulnerable people. There are many heat mitigation strategies for improving thermal comfort in urban areas. As human beings, it is our sacred duty to save the environment in which we live, but decision maker responsibility is much bigger because many remedial measures need to be implemented on a large scale. The application of MCDMs could be first approach that assists decision makers to quantitively assess the importance of criteria and the performance of alternatives in selection processes.

In previous studies, AHP-SWOT, multi-criteria outranking approach, EFDM, FDEMATEL, multi-criteria method by linear regression, TOPSIS, SMCE, Fuzzy-AHP TOPSIS have been used in the field of UHS [24]. In addition, the AHP method was specifically used to select the urban heat resilience intervention under certain criteria [25].

From the literature, it was investigated that most popular interventions considered to deal with thermal stress are white roofs, extensive green roofs, intensive green roofs [26], planting trees in cities [27], green parking lots, cool roofs, watering methods (sprays in public areas) [28], green walls, and shades. Figure 1 shows the interventions chosen for this study that can mitigate thermal discomfort in an urban setting.

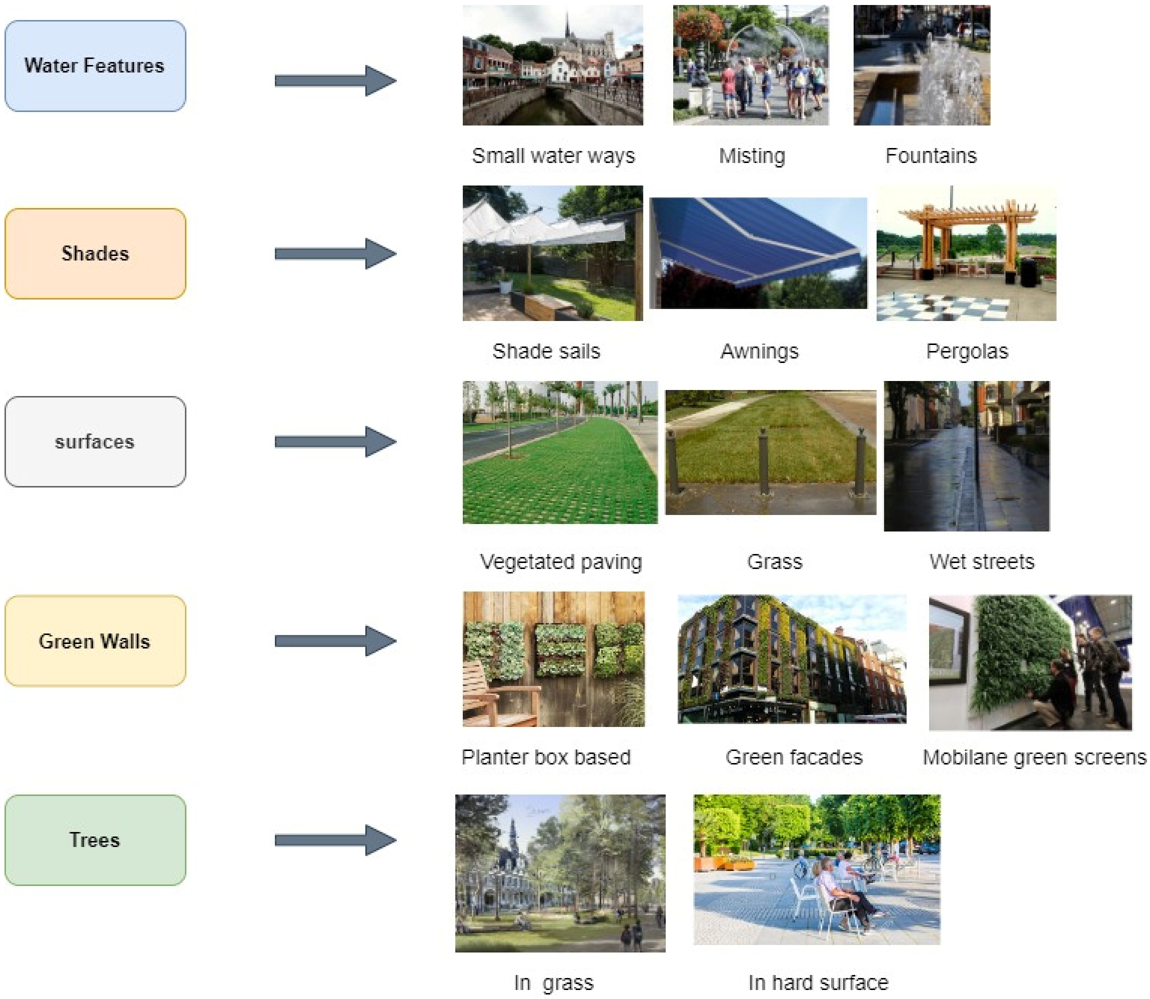

Figure 1. Type of heat resilience interventions.

For our studies, we considered four general criteria to address for the selection process of interventions (alternatives). These criteria are the following:

- *Cost*: capital and running cost of the intervention, which is often taken as a non-beneficial (NB) criterion.
- *Environment*: impact of the intervention on the level of air, land, and water. For example, it might be necessary to know if a recently introduced intervention significantly improves the previous mean level of air quality.
- *Efficiency*: cooling effect of intervention in open spaces.
- *Durability*: intervention capability to withstand the level of heat and remain useful without requiring additional maintenance after extreme weather events throughout the service life.

3. Mathematical Models of MCDMs

Eight different MCDMs and seven normalization methods were computed for deciding the UHS mitigation intervention. Additionally, the AHP was also applied for calculating the weightage of criteria. The procedure and key equations of methods are given in Table 1. Mathematical formulas of applied normalized methods are presented in Table 2.

Table 1. Key equations of MCDMs used in this study.

MCDM	Steps	Reference
TOPSIS: Technique for Order Preference by Similarity to Ideal Solutions	Step 1: make decision matrix Step 2: normalize decision matrix Step 3: weighted normalized decision matrix r_{ij}: normalized decision matrix $\mathcal{V}_{ij} = w_j r_{ij}$ w_j: weight of the Jth criteria (attribute) Condition $\sum_{j=1}^{n} w_j = 1$ Step 4: ideal best $\mathcal{V}_j^+$ and ideal worst $\mathcal{V}_j^-$ values If beneficial criteria: $\mathcal{V}_j^+ = \underset{i}{max}\left(v_{ij}\right) = max\left\{v_{ij}, i = 1, \ldots, m\right\}$ If cost criteria: $\mathcal{V}_j^+ = \underset{i}{min}\left(v_{ij}\right) = min\left\{v_{ij}, i = 1, \ldots, m\right\}$ Step 5: Calculate the distances of each alternative from the positive ideal solution and the negative ideal solution $S_i^{\pm} = \sqrt{\sum_{j=1}^{n}\left(\mathcal{V}_{ij} - \mathcal{V}_j^{\pm}\right)^2}$ Step 6: Calculate the relative closeness to the ideal solution (performance score) $R_i = \frac{S_i^-}{S_i^+ + S_i^-}$ Step 7: Ranking the best alternative	[29]
ELECTRE(NI-NS): Elimination and Choice Expressing Reality	Step 1: make decision matrix Step 2: normalize decision matrix Step 3: weighted normalized decision matrix $v_{ij} = R \times W = \begin{vmatrix} r_{11} \cdot \mathcal{W}_1 & r_{12} \cdot \mathcal{W}_2 & \text{K} & r_{1n} \cdot \mathcal{W}_n \\ r_{21} \cdot \mathcal{W}_1 & r_{22} \cdot \mathcal{W}_2 & \text{K} & r_{2n} \cdot \mathcal{W}_n \\ \text{K} & \text{K} & \text{K} & \text{K} \\ r_{m1} \cdot \mathcal{W}_1 & r_{m2} \cdot \mathcal{W}_2 & \text{K} & r_{mn} \cdot \mathcal{W}_n \end{vmatrix}$ Step 4: concordance and discordance interval sets $C_{ab} = \left\{j \mid v_{aj} \geq v_{bj}\right\}$ $D_{ab} = \left\{j \mid v_{aj} < v_{bj}\right\} = J - C_{ab}$ Step 5: calculation of the concordance interval matrix $C_{ab} = \sum_{j \in C_{ab}} \mathcal{W}_j$ $C = \begin{vmatrix} - & c(1,2) & \ldots & c(1,m) \\ c(2,1) & - & \ldots & c(2,m) \\ \vdots & \vdots & \vdots & \vdots \\ c(m,1) & c(m,2) & \ldots & - \end{vmatrix}$ Step 6: Determine the concordance index matrix $\bar{c} = \frac{\sum_{a=1}^{m} \sum_{b}^{m} c(a,b)}{m(m-1)}$ $e(a,b) = 1 \text{ if } c(a,b) \geq \bar{c}$ $e(a,b) = 0 \text{ if } c(a,b) < \bar{c}$ Step 7: Calculation of the discordance interval matrix $d(a,b) = \frac{\underset{j \in D_{ab}}{max}\left\|\mathcal{V}_{aj} - \mathcal{V}_{bj}\right\|}{\underset{j \in J_{mn}}{max}\left\|\mathcal{V}_{aj} - \mathcal{V}_{bj}\right\|}$ $D = \begin{vmatrix} - & d(1,2) & \ldots & d(1,m) \\ d(2,1) & - & \ldots & d(2,m) \\ \vdots & \vdots & \vdots & \vdots \\ d(m,1) & d(m,2) & \ldots & - \end{vmatrix}$	[30]

Table 1. *Cont.*

MCDM	Steps	Reference
	Step 8: determine the discordance index matrix $\bar{d} = \frac{\sum_{a=1}^{m}\sum_{b}^{m} d(a,b)}{m(m-1)}$ $f(a,b) = 1$ if $d(a,b) \leq \bar{d}$ $f(a,b) = 0$ if $d(a,b) > \bar{d}$ Step 9: calculate the net superior and inferior value $\mathcal{C}_a$: net superior $\mathcal{C}_a = \sum_{b=1}^{n} C(ab) - \sum_{b=1}^{n} C(ba)$ d_a: net inferior $d_a = \sum_{b=1}^{n} d(ab) - \sum_{b=1}^{n} d(ba)$ Step 10: select the best alternative choose highest value of net superior ($\mathcal{C}_a$) and lowest value of net inferior (d_a)	
PROMETHEE: This method utilizes a preferential function to drive the preference difference between alternative pairs.	Step 1: decision matrix Step 2: normalized the decision matrix Step 3: deviation by pairwise comparison $d_j(a,b) = R_j(a) - R_j(b)$ Step 4: preference function $p_j(a,b) = 0$ if $d_j(a,b) \leq 0$ $p_j(a,b) = d_j(a,b)$ if $d_j(a,b) > 0$ Step 5: multi-criteria preference index $pi_j(a,b) = \sum_{j=1}^{n} p(a,b)W_j$ Step 6: positive and negative outranking flows ($a \neq b$) $\phi^+(a) = \frac{1}{m-1}\sum_{b=1}^{n} pi(a,b)$ Step 7: net flow $\phi = \phi^+ - \phi^-$ Step 8: Ranking the best alternative by using highest value of net flow	[31]
VIKOR: multi-criteria optimization and compromise solution which focuses on ranking and selecting from a set of alternatives in the presence of conflicting criteria.	Step 1: Determine the objective and identify the pertinent evaluation attributes. Step 2: normalized decision matrix f Step 3: Find best and worst Best: $f_j^+ = \left(f_{ij}\right)_{max} = \max_i \left(f_{ij}\right)$ Beneficial attribute $f_j^+ = \left(f_{ij}\right)_{min} = \min_i \left(f_{ij}\right)$ Non beneficial attribute Worst: $f_j^- = \left(f_{ij}\right)_{min}$ Beneficial attribute $f_j^- = \left(f_{ij}\right)_{max}$ Non beneficial attribute Step 4: utility measure S_i and regret measure R_i $S_i = \sum_{j=1}^{n} w_j \left[\frac{f_j^+ - (f_{ij})}{f_j^+ - f_j^-}\right]$ $R_i = \max_j \left\{ w_j \left[\frac{f_j^+ - (f_{ij})}{f_j^+ - f_j^-}\right]\right\}$ Step 5: calculate the value of Q_i $Q_i = v\left[\frac{S_i - (S_i)_{min}}{(S_i)_{max} - (S_i)_{min}}\right] + (1-v)\left[\frac{R_i - (R_i)_{min}}{(R_i)_{max} - (R_i)_{min}}\right]$ $v = 0 \ldots 1$ generally taken as 0.5 Step 6: ranking the best alternative with lowest value of Q_i	[32]

Table 1. *Cont.*

MCDM	Steps	Reference
MOORA: Multi-Objective Optimization on the Basis of Ratio Analysis	Step 1: The alternatives and attributes values in the decision matrix: Step 2: Normalize decision matrix Step 3: positive and negative effects: maximization for beneficial criteria, minimization for non-beneficial (cost) $yb_i = \sum_{j=1}^{g} x_{ij}^* w_j$ $ynb_i = \sum_{j}^{n-g} x_{ij}^* w_j$ g is the number of criteria to be maximized $n-g$ is the number of criteria to be minimized x_{ij}^* is normalized decision matrix Step 4: determine the weighted assessment value $y_i = yb_i - ynb_i$ $y_i = \sum_{j-1}^{g} x_{ij}^* w_j - \sum_{j=1}^{n-g} x_{ij}^* w_j$ Step 5: ranking the best alternative Where alternative has the 1st rank with highest value of y_i	[33]
WSM: Weighted Sum Method	Step 1: make decision matrix. Step 2: normalized decision matrix Step 3: weighted normalized decision matrix r_{ij}: normalized decision matrix $v(i,j) = r(i,j).w(j)$ Step 4: weighted sum $ws(i) = \sum_{j=1}^{n} v(i,j)$ Step 5: ranking the best alternative	[34]
WPM: Weighted Product Method	Step 1–3: same as WSM Step 4: weighted product $wp(i) = \prod_{j=1}^{n} v(i,j)$ Step 5: ranking the best alternative	
AHP	Step 1: Pair-wise comparison matrix of criteria or alternatives $P(i) = \prod_{j=1}^{n} A(i,j)$ $Pn(i) = (P(i))^{1/N}$ $Pn(i) = \left(\prod_{j=1}^{n} A(i,j)\right)^{1/N}$ $sp = \sum_{i=1}^{m} Pn(i)$ Step 2: Criteria weights or alternatives scores: $w(i) = Pn(i)/sp$ Step 3: Calculate consistency $w(i) = w(j)$, where $n = m$ size of A matrix $v(i,j) = x(i,j).w(j)$ Step 4: calculate weighted sum value: $sw(i) = \sum_{j=1}^{n} v(i,j)$ Step 5: calculate consistency error $R(i) = sw(i)/w(i)$ $\lambda \sum_{i=1}^{m} R(i)/m_{max}$ $CI = \frac{\lambda_{max}-n}{n-1}$ For $n = 4$, $Ri = 0.9$	

Table 2. Mathematical formulas of different normalization methods.

Normalization	Abbreviation	Beneficial	Non-Beneficial
Linear	$L_{N\text{-}i}$	$\overline{X}_{ij} = \frac{X_{ij}}{X_j^{max}}$	$\overline{X}_{ij} = 1 - \frac{X_{ij}}{X_j^{max}}$
	$L_{N\text{-}ii}$	$\overline{X}_{ij} = \frac{X_{ij}}{X_j^{max}}$	$\overline{X}_{ij} = \frac{X_j^{min}}{X_{ij}}$
	$L_{N\text{-}max\text{-}min}$	$\overline{X}_{ij} = \frac{X_{ij} - X_j^{min}}{X_j^{max} - X_j^{min}}$	$\overline{X}_{ij} = \frac{X_j^{max} - X_{ij}}{X_j^{max} - X_j^{min}}$
	$L_{N\text{-}Sum}$	$\overline{X}_{ij} = \frac{X_{ij}}{\sum_{i=1}^{m} X_{ij}}$	$\overline{X}_{ij} = \frac{\frac{1}{X_{ij}}}{\sum_{i=1}^{m}\left(\frac{1}{X_{ij}}\right)}$
Enhanced accuracy	E_{AN}	$\overline{X}_{ij} = 1 - \frac{X_j^{max} - X_{ij}}{\sum_{i=1}^{m}\left(X_j^{max} - X_{ij}\right)}$	$\overline{X}_{ij} = 1 - \frac{X_{ij} - X_j^{min}}{\sum_{i=1}^{m}\sum\left(X_{ij} - X_j^{min}\right)}$
Logarithmic	L_{nN}	$\overline{X}_{ij} = \frac{lnX_{ij}}{ln(\Pi_{i=1}^{m} X_{ij})}$	$\overline{X}_{ij} = 1 - \frac{1 - \frac{lnX_{ij}}{ln(\Pi_{i=1}^{m} X_{ij})}}{m-1}$
Vector	V_N	$\overline{X}_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}^2}}$	$\overline{X}_{ij} = 1 - \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}^2}}$

4. Research Methodology

The collection of human perspectives is the first step for implementing any MCDM. The survey was distributed with the explanation of the purpose of the study. Participants were asked to participate in quantitative judgment using the linguistic scale, shown in Figure 2, to assess the importance of criteria and the performance of alternatives (interventions) for UHS mitigation. The experts belonged to academics in the field of urban climate.

Figure 2. Linguistic scale for rating the importance of criteria and performance of alternatives.

The collected questionnaires were checked, and assessments that contained inconsistencies were discarded and not used for further analysis. After this quality check, it was observed that 25 ratings could be useful. These judgments were aggregated using geometric means and then MCDMs, such as ELECTRE-NS, ELECTRE-NI, MOORA, PROMETHEE, TOPSIS, VIKOR, WPM, and WSM, were applied to prioritize the UHS mitigation alternatives (A1, A2 . . .). These methods were implemented in two ways: stand-alone, where direct criteria weights were used, and coupled with AHP (criteria weights calculated by AHP using the judgment matrix shown in Table 3). Seven different normalization methods were used for the simple application of MCDMs (stand-alone). The research methodology is shown in Figure 3.

Table 3. Criteria weight matrix by AHP.

Criteria	Cost	Efficiency	Durability	Environment Impacts
Cost	1	2	3	2
Efficiency	1/2	1	2	1
Durability	1/3	1/2	1	1/2
Environment	1/2	1	2	1

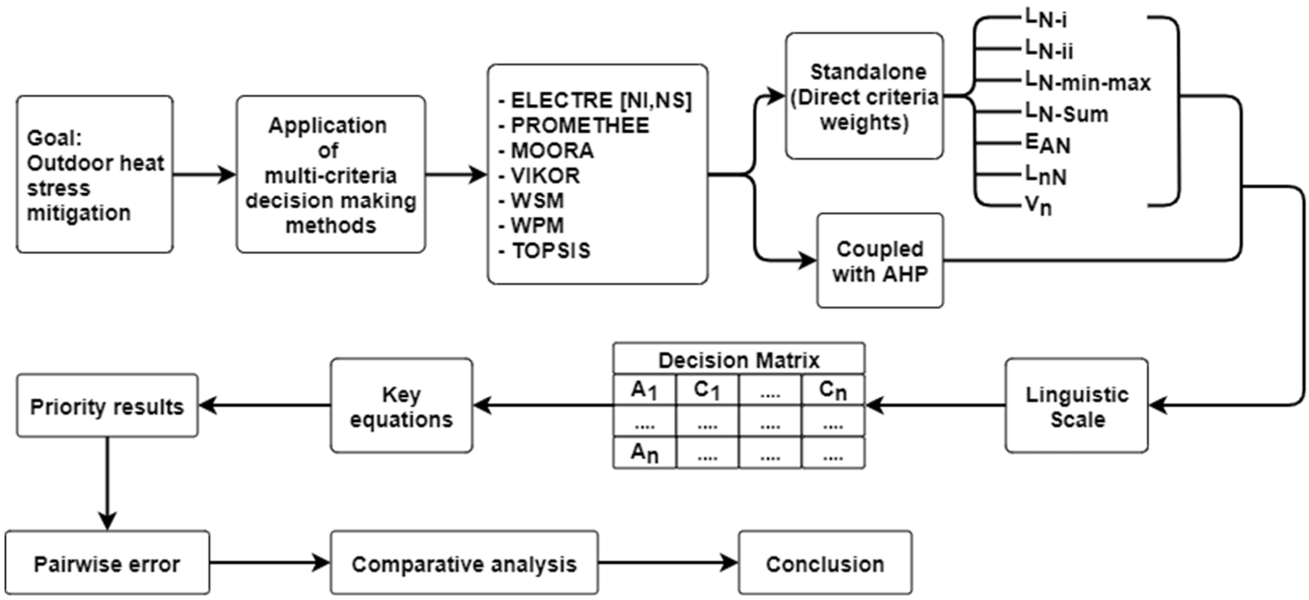

Figure 3. Research methodology.

The inputs for criteria and alternatives using the linguistic scale 1–10 was used, where high value of scale represents the high importance; for example, cost is a non-beneficial criterion, and in the case of shades the score was 8, which means it is very expensive, but the durability score was 5, which means that sometimes shades require maintenance after windstorms. All inputs were formulated in the decision matrix shown in Table 4, where criteria weights are given by direct method for the stand-alone application, and criteria weights are calculated by AHP for the combined approach by using the related formulas in Table 1.

Table 4. Decision matrix.

Direct weightage	0.45	0.15	0.20	0.20
Weightage by AHP	0.42	0.23	0.12	0.23
Interventions/Criteria	Cost	Efficiency	Durability	Environment Impacts
Water features	6	4	4	5
Surfaces	5	4	5	3
Green walls	7	6	6	7
Trees	4	7	8	8
Shades (shelter canopies)	8	4	5	2
	NB	B	B	B

5. Results

5.1. Comparative Analysis of Normalization Methods for Applied MCDM

The results show that the logarithmic normalization method had no impact on the ranking results calculated by the applied MCDMs (except for ELECTRE and VIKOR) when compared to other normalization methods. In contrast, the same ranking was observed in PROMETHEE and WSM results using all normalization techniques. Table 5 shows the consistency of similar ranking results using MCDMs under different normalization techniques.

Table 5. Comparative analysis of normalization methods.

Name	Results Consistency
$L_{N\text{-}i}$	ELE-NS, ELE-NI, PROMETHEE, WSM
$L_{N\text{-}ii}$	ELE-NS, ELE-NI, PROMETHEE, WSM
$L_{N\text{-max-min}}$	ELE-NS, PROMETHEE, WSM
E_{AN}	ELE-NS, PROM, WSM, WPM
L_{nN}	WSM, WPM, TOPSIS, PROMETHEE, MOORA
V_N	WSM, PROMETHEE, ELE-NS
$L_{N\text{-Sum}}$	WSM, PROMETHEE, ELE-NS, ELE-NI

5.2. Priority Ranking

The priority ranking for the selection of heat resilience interventions were calculated by using direct and AHP criteria weights. The ranking results obtained by stand-alone MCDM using L_{nN} and AHP-MCDM are shown in Tables 6 and 7, where alternative A1 is water feature, A2 is surfaces, A3 is green wall, A4 is trees, and A5 is shades, respectively.

Table 6. Rank calculated using MCDMs with L_{nN} method for normalization.

Methods	Alternatives/Interventions Priority Results				
	A1	A2	A3	A4	A5
1—ELE-NS	3	5	1	2	4
2—ELE-NI	4	5	1	3	2
3—MOORA	2	3	4	1	5
4—PROMETHEE	4	5	1	2	3
5—TOPSIS	3	2	4	1	5
6—VIKOR	2	3	5	1	4
7—WPM	4	5	1	2	3
8—WSM	4	5	1	2	3

Table 7. Rank calculated by AHP-MCDM.

Methods	Alternatives/Interventions Priority Results				
	A1	A2	A3	A4	A5
1—ELE-NS	4	5	1	2	3
2—ELE-NI	3	4	1	2	5
3—MOORA	3	4	2	1	5
4—PROMETHEE	3	4	2	1	5
5—TOPSIS	3	4	2	1	5
6—VIKOR	3	2	4	1	5
7—WPM	3	4	2	1	5
8—WSM	3	4	2	1	5

5.3. Ranking Frequency Error of Stand-Alone MCDMs and AHP-MCDMs

The obtained ranking results were showing frequency errors when comparing each applied method, which could mislead the decision. This problem was solved by evaluating the frequency of the same rankings. The pairwise frequency error was calculated by Equations (1) and (2). The sum of the standard deviation defines the frequency error and assist to observe the variation in decision by applying different MCDMs using the same judgments. The method aims to check the consistency of the results and to evaluate the reliability of outcomes. The ends results are shown in the pairwise matrices in Table 8.

$$E_{ij} = \sqrt{\sum_{k=1}^{5} \left(A_{kM_i} - A_{kM_j} \right)^2} \quad (1)$$

$$E_j = \sum_{i=1}^{8} E_{ij} \quad (2)$$

where: $i =$ no of rows, $j =$ no of columns, $k =$ no of alternatives, $M =$ no of methods, A = ranking result of alternative, and E_j = sum of the variation in ranking results.

Table 8. Pairwise comparison of frequency error matrix.

Ranking Frequency of Standalone MCDM								
	ELE-NS	ELE-NI	MOORA	PROMETHEE	TOPSIS	VIKOR	WPM	WSM
ELE-NS	0	2.45	4	1.41	4.47	4.69	1.41	1.41
ELE-NI	2.45	0	5.48	1.41	5.66	5.66	1.41	1.41
MOORA	4	5.48	0	4.69	1.41	1.41	4.69	4.69
PROMETHEE	1.41	1.41	4.69	0	4.90	5.10	0	0
TOPSIS	4.47	5.66	1.41	4.90	0	2	4.90	4.90
VIKOR	4.69	5.66	1.41	5.10	2	0	5.10	5.10
WPM	1.41	1.41	4.69	0	4.90	5.10	0	0
WSM	1.41	1.41	4.69	0	4.90	5.10	0	0
Sum	19	23.48	26.37	17.5	28.24	29.06	17.5	17.5
Ranking Frequency of AHP-MCDM								
	ELE-NS	ELE-NI	MOORA	PROMETHEE	TOPSIS	VIKOR	WPM	WSM
ELE-NS	0	2.45	2.83	2.83	2.83	4.90	2.83	2.83
ELE-NI	2.45	0	1.41	1.41	1.41	3.74	1.41	1.41
MOORA	2.83	1.41	0	0	0	2.83	0	0
PROMETHEE	2.83	1.41	0	0	0	2.83	0	0
TOPSIS	2.83	1.41	0	0	0	2.83	0	0
VIKOR	4.90	3.74	2.83	2.83	2.83	0	2.83	2.83
WPM	2.83	1.41	0	0	0	2.83	0	0
WSM	2.83	1.41	0	0	0	2.83	0	0
Sum	21.5	13.24	7.07	7.07	7.07	22.79	7.07	7.07

6. Discussion

The applied MCDMs were analyzed by considering three criteria in negative and positive attributes (presented in Table 9) which are:

- *Normalization*: Positive evaluation is performed for MCDMs that gives the same results under different normalization techniques, where variations in results are taken as negative.
- *MCDM Frequency*: similar ranking results obtained by stand-alone MCDMs are assessed as positive, and high variations are considered as negative.
- *AHP-MCDM Frequency*: this criterion is used to investigate the impact of coupling AHP with applied MCDMs, where positive and negative signs show the decrease and increase in frequency variation of final ranking results, respectively.

Table 9. Comparative analysis of MCDM.

Methods	Assessment		
	Normalization	Frequency Error	
		MCDM	AHP-MCDM
TOPSIS	-	-	+
MOORA	-	-	+
PROMETHEE	+	+	+
WPM	-	+	+
WSM	+	+	+
VIKOR	-	-	+
ELE-NS	+	+	-
ELE-NI	-	-	+

The frequency error in the ranking results is illustrated in Figure 4, which shows that AHP helps to reduce the irregularity of the final ranking due to the pairwise subjective judgment for calculating criteria weights, which makes more reliable results in decision-making. It is compatible to combine with all the methods except ELECTRE-NS. The increased frequency error in ranking was noticed when the ELECTRE-NS model was coupled with the AHP. It was observed that WSM and PROMETHEE were not affected using any normalization techniques and gave the same ranking, which proves that they are the most reliable methods. Moreover, TOPSIS, MOORA and VIKOR models provided improved results after coupling, but the different normalization techniques could affect the final outcome.

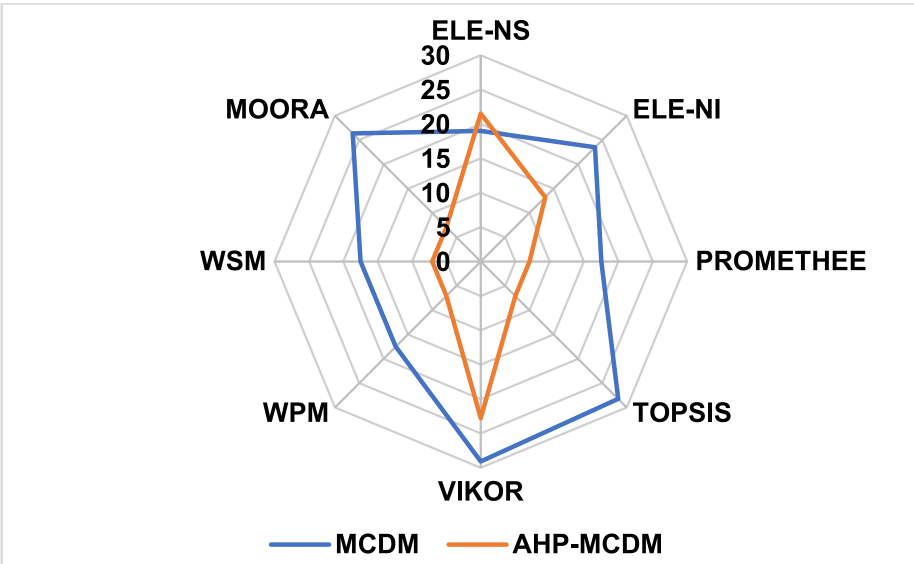

Figure 4. Graph of calculated error in pairs.

Based on provided judgments (Table 4), the priority ranking obtained from the majority of the MCDMs showed that planting trees in the urban area was an effective cooling strategy that provides shade, improves air quality, and gives good cooling in certain areas where green walls improve indoor and outdoor air temperature. Additionally, the green walls enhance the aesthetics of the property. The watering method to wet the streets in the summer, planting grass on the surfaces, and water features such as fountains provides the limited cooling extent and requires extra care. While artificial shadings are expensive to install in hotspots, there was no co-benefit associated with this intervention.

7. Conclusions

This study was performed for the selection of intervention to mitigate outdoor UHS by applying multiple MCDMs. Eight different well known and classical techniques were computed to evaluate the priority ranking of interventions. A major concern with decision-making is that different MCDM methods provide different results for the same problem. For reliability of the outcomes, a comparative study was conducted on the basis of three criteria, which were (i) influence of normalization techniques, frequency of similar ranking results by (ii) stand-alone MCDMs, and (iii) AHP-MCDM application. It was observed that PROMETHEE and WSM were reliable methods in this field among other applied MCDMs, namely, MOORA, WPM, ELECTRE-NS, ELECTRE-NI, TOPSIS, VIKOR, which are sensitive methods and, due to variations, these MCDM models provided different priority results. Additionally, the L_{nN} was a more reasonable normalization technique, and it provided similar rankings in the majority of applied MCDMs. It was noticed that the coupling of AHP helped to minimize the frequency error through the pairwise method for criteria weights, which increased the reliability of the decision.

In this study, the priority of green walls and trees is an arbitrary output of decision makers. The ranking obtained on the parameters was not a general rule, and this procedure was carried out to check the reliability. The results were entirely based on the terrain, the perspectives, characteristics of the pilots, climatic conditions, and inputs of the decision-makers.

The improved frequency of consistent results by AHP-MCDM revealed that the ranking results mainly depended on the nature and the values of the criteria. The reasonable disagreement that was observed among the methods did not affect their reliability. As a result, MCDM models proved generally very effective for dealing with UHS problems before their implementation and selection of the best ones.

However, a possible limitation of this work is that this comparative conclusion is based only on the evaluation of ranking errors. Future works are to extend the experiment with more MCDM models and to perform sensitivity analysis to confirm that the results would not change.

Author Contributions: The paper was a collaborative effort between the authors. A.M.Q. and A.R. contributed collectively to developing the methodology of this study, analysis, development of HVI and the manuscript preparation. All authors have read and agreed to the published version of the manuscript.

Funding: This paper has been produced within the COOL-TOWNS (Spatial Adaptation for Heat Resilience in Small and Medium Sized Cities in the 2 Seas Region) project which receives funding from the Interreg 2 Seas programme 2014–2020 co-funded by the European Regional Development Fund under subsidy contract N° 2S05-040.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

AHP	Analytic hierarchy process
EFDM	Enhanced fuzzy Delphi method
FDEMATEL	Fuzzy decision-making trial and evaluation laboratory
SMCE	Spatial Multi-Criteria Evaluation
NI	Net inferior
NS	Net superior
SWOT	Strength weakness opportunities and threat
DEA	Data envelopment analysis
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluation

VIKOR	Viekriterijumsko Kompromisno Rangiranje
MOORA	Multi-Objective Optimization Ratio Analysis
MCDA	Multi Criteria Decision Analysis

References

1. Ansari, A.Q. The basics of fuzzy logic: A tutorial review. *Comput. Educ. Staff. Comput. Educ. Group* **1998**, *88*, 5–8.
2. McBratney, A.; Odeh, I.O. Application of fuzzy sets in soil science: Fuzzy logic, fuzzy measurements and fuzzy decisions. *Geoderma* **1997**, *77*, 85–113. [CrossRef]
3. Ordoobadi, S.M. Development of a supplier selection model using fuzzy logic. *Supply Chain Manag. Int. J.* **2009**, *14*, 314–327. [CrossRef]
4. De Korvin, A.; Strawser, J.; Siegel, P.H. An Application of Control System to Cost Variance Analysis. *Manag. Finance* **1995**, *21*, 17–35. [CrossRef]
5. Tanaka, H.; Okuda, T.; Asai, K. A formulation of fuzzy decision problems and its application to an investment problem. *Kybernetes* **1976**, *5*, 25–30. [CrossRef]
6. Gunasekaran, N.; Rathesh, S.; Arunachalam, S.; Koh, S. Optimizing supply chain management using fuzzy approach. *J. Manuf. Technol. Manag.* **2006**, *17*, 737–749. [CrossRef]
7. Chan, D.C.; Yung, K.L.; Lp, A.W.H. An application of fuzzy sets to process performance evaluation. *Integr. Manuf. Syst.* **2002**, *13*, 237–283. [CrossRef]
8. Khaira, A.; Dwivedi, R.K. A State-of-the-Art Review of Analytical Hierarchy Process. *Mater. Today Proc.* **2018**, *5*, 4029–4035. [CrossRef]
9. Kusumawardani, R.P.; Agintiara, M. Application of Fuzzy AHP-TOPSIS Method for Decision Making in Human Resource Manager Selection Process. *Procedia Comput. Sci.* **2015**, *72*, 638–646. [CrossRef]
10. Jurík, L.; Horňáková, N.; Šantavá, E.; Cagáňová, D.; Sablik, J. Application of AHP method for project selection in the context of sustainable development. *Wirel. Netw.* **2020**, *28*, 893–902. [CrossRef]
11. Calabrese, A.; Costa, R.; Levialdi, N.; Menichini, T. Integrating sustainability into strategic decision-making: A fuzzy AHP method for the selection of relevant sustainability issues. *Technol. Forecast. Soc. Chang.* **2018**, *139*, 155–168. [CrossRef]
12. Stojčić, M.; Zavadskas, E.K.; Pamučar, D.; Stević, Ž.; Mardani, A. Application of MCDM Methods in Sustainability Engineering: A Literature Review 2008–2018. *Symmetry* **2019**, *11*, 350. [CrossRef]
13. Waris, M.; Panigrahi, S.; Mengal, A.; Soomro, M.I.; Mirjat, N.H.; Ullah, M.; Azlan, Z.S.; Khan, A. An Application of Analytic Hierarchy Process (AHP) for Sustainable Procurement of Construction Equipment: Multicriteria-Based Decision Framework for Malaysia. *Math. Probl. Eng.* **2019**, *2019*, 6391431. [CrossRef]
14. Moslem, S.; Çelikbilek, Y. An integrated grey AHP-MOORA model for ameliorating public transport service quality. *Eur. Transp. Res. Rev.* **2020**, *12*, 68. [CrossRef]
15. Mojaheed, M.; Marjani, M.E.; Afshari, A.R.; Marjani, S. Using ELECTRE-AHP as a mixed method for personnel selection. In Proceedings of the Traineeational Symposium on the Analytic Hierarchy Process, Kuala Lumpur, Malaysia, 23–26 June 2013. [CrossRef]
16. Maheshwarkar, M.; Sohani, N. Combined AHP-TOPSIS based approach for the evaluation of knowledge sharing capabilities of supply chain partners. *Manag. Sci. Eng.* **2013**, *7*, 27–32.
17. Dinmohammadi, A.; Shafiee, M. Determination of the Most Suitable Technology Transfer Strategy for Wind Turbines Using an Integrated AHP-TOPSIS Decision Model. *Energies* **2017**, *10*, 642. [CrossRef]
18. Turcksin, L.; Bernardini, A.; Macharis, C. A combined AHP-PROMETHEE approach for selecting the most appropriate policy scenario to stimulate a clean vehicle fleet. *Procedia Soc. Behav. Sci.* **2011**, *20*, 954–965. [CrossRef]
19. Waas, D.V.; Suprapto, S. Combination of AHP method and vikor method for assesing sunday school teacher. *IJCCS Indones. J. Comput. Cybern. Syst.* **2020**, *14*, 45–56. [CrossRef]
20. Combined AHP-WSM Based Approach for the Evaluation of Knowledge Sharing Capabilities of Supply Chain Patterns. Available online: https://www.researchgate.net/publication/234032617_Combined_AHP-WSM_based_approach_for_the_evaluation_of_knowledge_sharing_capabilities_of_supply_chain_patterns (accessed on 7 October 2022).
21. Zaidan, A.; Zaidan, B.; Hussain, M.; Haiqi, A.; Kiah, M.M.; Abdulnabi, M. Multi-criteria analysis for OS-EMR software selection problem: A comparative study. *Decis. Support Syst.* **2015**, *78*, 15–27. [CrossRef]
22. Ahmad, N.; Berg, D.; Simons, G.R. The integration of analytical hierarchy process and data envelopment analysis in a multi-criteria decision-making problem. *Int. J. Inf. Technol. Decis. Mak.* **2006**, *5*, 263–276. [CrossRef]
23. Asadabadi, M.R.; Chang, E.; Saberi, M. Are MCDM methods useful? A critical review of Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP). *Cogent Eng.* **2019**, *6*, 1623153. [CrossRef]
24. Qureshi, A.M.; Rachid, A. Review and Comparative Study of Decision Support Tools for the Mitigation of Urban Heat Stress. *Climate* **2021**, *9*, 102. [CrossRef]
25. Qureshi, A.M.; Rachid, A. An Analytic Hierarchy Process for urban heat stress mitigation. In Proceedings of the 2022 2nd International Conference on Digital Futures and Transformative Technologies (ICoDT2), Rawalpindi, Pakistan, 24–26 May 2022; pp. 1–6. [CrossRef]

26. Using Green Roofs to Reduce Heat Islands. Available online: https://www.epa.gov/heat-islands/using-green-roofs-reduce-heat-islands (accessed on 4 April 2022).
27. Using Trees and Vegetation to Reduce Heat Islands. Available online: https://www.epa.gov/heat-islands/using-trees-and-vegetation-reduce-heat-islands (accessed on 4 April 2022).
28. Hendel, M. Pavement-Watering for Cooling the Built Environment: A Review. 2016. Hal-01426167. Available online: https://hal.archives-ouvertes.fr/hal-01426167/ (accessed on 2 July 2022).
29. Uzun, B.; Taiwo, M.; Syidanova, A.; Ozsahin, D.U. The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). In *Application of Multi-Criteria Decision Analysis in Environmental and Civil Engineering. Professional Practice in Earth Sciences*; Uzun Ozsahin, D., Gökçekuş, H., Uzun, B., LaMoreaux, J., Eds.; Springer: Cham, Switzerland, 2021; pp. 25–30. [CrossRef]
30. Roy, B.; Skalka, J. *ELECTRE IS: Aspects Méthodologiques et Guide D'utilisation*; Université de Paris Dauphine: Paris, France, 1987. Available online: https://books.google.com.hk/books?id=iAPxHAAACAAJ (accessed on 2 July 2022).
31. Brans, J.P.; Vincke, P.; Mareschal, B. How to select and how to rank projects: The Promethee method. *Eur. J. Oper. Res.* **1986**, *24*, 228–238. [CrossRef]
32. Yazdani, M.; Graeml, F.R. VIKOR and its applications: A state-of-the-art survey. *Int. J. Strateg. Decis. Sci. IJSDS* **2014**, *5*, 56–83. [CrossRef]
33. Chakraborty, S. Applications of the MOORA method for decision making in manufacturing environment. *Int. J. Adv. Manuf. Technol.* **2010**, *54*, 1155–1166. [CrossRef]
34. Chourabi, Z.; Khedher, F.; Babay, A.; Cheikhrouhou, M. Multi-criteria decision making in workforce choice using AHP, WSM and WPM. *J. Text. Inst.* **2018**, *110*, 1092–1101. [CrossRef]