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Customisation of green buildings assessment tools based on climatic zoning and experts judgement using *K*-means clustering and fuzzy AHP

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A R T I C L E I N F O

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A B S T R A C T

Utilising green building regulations and classifications by using well-known assessment tools such as LEED can be challenging in a country with various climates due mainly to specific sustainability priorities for each climate. This paper presents a new framework to customise assessment tools of green buildings for regions or countries with various climates. The framework comprises *K*-means method to cluster various climates of the region combined with the silhouette value (SV) for clustering verification and local experts' judgement for local customisation of green building assessment tools. The Fuzzy analytical hierarchy process (AHP) is used to adjust the regulations for each climatic zone. The proposed methodology is demonstrated by its application to the real-world case study of Iran. The *K*-means clustering with SV divides the country into four distinct climatic zones each representing with four meteorological parameters (MP, DTR, CDD, and HDD). Results show each climatic zone can take weights for sustainability categories and criteria based on its climate e.g. higher weight for "Water Efficiency" in zones with low rainfall and higher weight for "Energy and Atmosphere" in zones with heating or cooling needs. Results also show the two categories of "Energy and Atmosphere" and "Water Efficiency" take the largest weights in all zones by an average of almost 27 and 26%. These two categories, alongside with "Sustainable Site", had the most changes in their weights for each climatic zone. The findings of this research reveal the effects of local climates on sustainability priorities of a green building assessment tool.

1. Introduction

In the late 80s, the universal movement has begun to go through the path of sustainability. In the meantime, researchers have been trying to introduce new green technologies and strategies to employ renewable and sustainable resources and reduce carbon footprint and greenhouse gas emissions [1]. The concept of sustainability has become an indispensable part of the building industry [2] due to its significant impact on the natural environment [3]. For instance, more than one-third of the total world energy consumption and greenhouse gas emissions are generated through the life cycle of buildings from construction to operation, demolition and disposal [4]. Hence, sustainable (or green) buildings have gained recognition to overcome these issues by taking proper measures [5,6].

Green buildings are now considered an essential element towards sustainable development. A green building is typically defined to be an environmentally friendly and energy-efficient structure, operating sustainably for the consumption of energy, water and other resources with the minimum generation of wastewater and solid waste as well as resource recovery and reuse such as rainwater harvesting, greywater recycling, anaerobic digestion and composting [7]. In general, water and energy efficiency, durability, occupants' comfort, and a high proportion of recyclable materials are the most important characteristics of green buildings [8]. Official organisations, independent institutes and many researchers also work on sustainability indicators and assessment criteria which have led to several green buildings evaluation tools [9]. During the past decades, two types of building sustainability assessment tools have emerged. The first type is based on the system criteria defined for a project while the second one relies on life cycle assessment (LCA) methodologies. The criteria-based tools are basically point-based

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systems for a set of pre-defined indicators that finally reward a project based on the level of reduction in environmental impacts [8]. Some examples of criteria-based Green Buildings Assessment Tools (GBATs) are Building Research Establishment Environmental Assessment Method (BREEAM) in the UK, Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) in Japan, Green Building Tool (GBTool) of Multinational collaboration, Leadership in Energy and Environmental Design (LEED) in the US, Green Standard for Energy and Environmental Design (G-SEED) in South Korea, and Green Star Rating Tools (Green Star) in Australia [10]. On the other hand, LCA methods are widely used to select building design and material and local utility initiatives, including energy production, waste management, and transport alternatives during the design phase [11].

Employing GBATs can result in better building performance at all stages of its life cycle compared to conventional practices [8]. Several criteria-based assessment tools introduced by developed countries such as those aforementioned examples comprise indicators and parameters with unique point-based assignment patterns mainly based on local sustainability priorities [12]. The tools developed by these countries have already been customised by their own national expert teams and hence there may not need to use the tools developed by other countries. However, due to the high demand of using these tools in many countries in the world to achieve sustainability in the building sector, currently developed tools can be of interest to other counties especially developing countries with no customisation of any national tools for the assessment of their green buildings. Some of these tools have been popular and used widely on an international scale, e.g. buildings evaluated by LEED are used in more than 164 countries [13]. The concept of sustainability in the building sector includes a wide range of considerations from water and energy efficiency to materials and site-related issues. Climate variations can have a crucial impact on sustainability priorities in the building sector. For example, the significance of water efficiency in hot and arid regions (e.g. many parts of countries in the Middle East) are far greater than moderate regions with high annual precipitation. In addition, sustainability priorities usually vary in different countries and hence customisation of sustainability priorities may be necessary when using a tool developed by other countries due to the unique geographical, climatic, culture, and economic features of the new countries [14].

Several developing countries have customised well-known green building assessment tools focusing on regional sustainability initiatives. Table 1 shows a summary of recent studies for customising well-known GBATs and the methods applied for these customisations.

As can be seen in the table, multiple research works used Multi-Criteria Decision-Making (MCDM) methods for customising well-known green building assessments tools. MCDM has been conceived as a reliable Decision Making (DM) tool since the beginning of the 1970s, involving both quantitative and qualitative factors [37]. Several MCDM methods widely used here include AHP (analytic hierarchy process), ANP (analytic network process), ELECTRE (elimination Et choice translating), PROMETHEE (preference ranking organisation method), TOPSIS (a technique for order preference by similarity to ideal solution), and so on [38]. Some problems associated with using some MCDM methods have been reported [21]. For example, the TOPSIS method has the problem of unsatisfactory consistency of the experts' judgements and the weight assignment method in PROMETHEE is relatively vague [39]. On the other hand, according to Saaty (2008) [40], AHP is a powerful tool to address difficult DM issues, and it employs pair-wise comparisons to obtain the importance of desired factors. In addition, this method has been widely used in multiple cases for the green building research [41,42] and hence, the AHP seems to be a desirable method for such a group decision making with multiple criteria. Despite the merits of the AHP, its application may pose some issues outlined here. Firstly, due to the hierarchical structure of the model, a large number of enquiries need to be answered that may increase the uncertainty of decision-making process. This is especially important when it

Table 1
Recent studies on the customisation of well-known green building assessment tools with regional priorities.

No	Tool/method	Summary	Country	Ref.
1	MCDM - AHP	Proposing a method for localisation of international green building regulations for developing countries and introducing sustainable priorities	Jordan	[8]
2	Comparison with China Green Building Label (GBL)/Delphi	Localisation of China Green Building Regulations for Hong Kong Island with Attention to local challenges	Hong Kong	[15]
3	Weighted and non-weighted classification	Comparative study between international green building regulations and Portugal's green building regulations with a focus on energy efficiency	Portugal	[16]
4	Direct Comparison	Building sustainability objective assessment in Estonian context and a comparative evaluation with LEED and BREEAM	Estonia	[17]
5	Cross-disciplinary criteria	Proposing a rating system named BRAVE for integrating building performance tools in developing countries	Colombia, Qatar, Jordan	[18]
6	Likert Scale	Comparing the implementation of valid international regulations and proposing new regulations considering local conditions	India	[19]
7	Direct & Indirect Comparison	Comparing local and international Green Building assessment tools with existing regulations to find practical limitations	Nigeria	[20]
8	MCDM - AHP/Weighted Harmonic Mean/ Shannon's Entropy	Reviewing of international regulations and previous studies and providing suggestions in order to weigh local regulations for office buildings	Iran	[14]
9	MCDM - Fuzzy AHP (FAHP)	Combining criteria and indices of international regulations and presentation suggestion regarding the weighting of an indigenous regulation named ISAT for newly built residential buildings	Iran	[21]
10	MCDM - Fuzzy AHP (FAHP)	Proposing six criteria and 95 indices for developing Green School regulations	Iran	[22]
11	Delphi	Benchmarking critical criteria for rating sustainability of buildings in a tropical climate	India	[23]
12	Likert Scale	Identifying and Prioritising Green Building Parameters considering Sustainable	Iran	[24]

(continued on next page)

Table 1 (*continued*)

No	Tool/method	Summary	Country	Ref.
		Development with a focus on Energy consumption optimisation		
13	Partial Least Squares Path Modelling	Investigation of sociological and psychological factors of failure of Green Building concepts	Iran	[25]
14	Delphi – FD-AHP – Scenario analysis	Development of a sustainability assessment guideline for decision makers	South Korea	[26]
15	LCA	Investigating the importance of the sustainability indicators in building industry, across the whole life cycle	Ghana	[27]
16	AHP	Proposing a novel green building rating tool for the existing buildings	Egypt	[28]
17	AHP	Proposing a methodology for the sustainability assessment of buildings in the design phase	Slovenia	[29]
18	ARAS (Additive Ratio Assessment) – AHP	Selecting the Criteria for buildings' sustainability assessment	Sweden	[30]
19	SI (Severity Index) – Exploratory factor analysis	Determining the important sustainability criteria for office and administrative buildings	Saudi Arabia	[31]
20	Neighbourhood sustainability assessment	Evaluation and comparison of the sustainability of the residential buildings	Malaysia	[32]
21	Individual Interview Technique	Investigation of energy efficiency criteria in green buildings and identification and prioritising important sub-criteria	Iran	[33]
22	Qualitative Approach	Assessing the quality and capability of world-renowned ranking systems including ISCA, LEED-ND, CASBEE, Green star, DGNB, and BREEAM using as a reference for sustainable development	Iran	[34]
23	Analysis of Variance (ANOVA)	Investigating the points obtained according to LEED in different projects and their success in satisfying the requirements of the LEED	US	[35]
24	Average Point/Shapiro-Wilk test/Kruskal-Wallis one-way Analysis/Generalised Additive Model (GAM)	Differences in scores obtained from LEED 2009 in various countries	US, China, Turkey, and Brazil	[36]

comes to green building assessment tools with a large number of categories and criteria that requires a considerable number of pairwise comparisons. Although the inconsistency ratio of the pair-wise comparisons is limited, it would be difficult to ensure the overall uncertainty of the decision-making is minimised due to subjective nature of input taken from the respondents' judgements. Moreover, classic AHP fails to satisfy the fuzziness of human subjective judgments properly. This problem was mainly addressed by combining AHP with fuzzy logic to assist respondents in expressing their judgements in a more decisive way by using linguistic terms which can result in reducing the level of vagueness [43].

In addition to the need for customising GBATs in a new country, the unique features of climate, economy and culture of different regions of the country should be included properly. Hence, the design of a universal GBAT to adequately include all sustainability perspectives on a regional scale can be challenging [36]. Besides, available resources to achieve sustainable buildings may vary greatly in different regions. In other words, the significant impact of the natural environment and culture on human behaviour of a region such as energy consumption, construction methods and materials needs to be considered carefully within the customisation of the GBAT design [44]. However, well-known assessment tools such as LEED give little attention to the matters of geographical and climatic differences [45]. For example, based on the LEED for existing buildings (2009) [46], climatic and geographical differences were barely recognised in the regulations. More specifically, buildings with the same design and construction method but located in different climatic regions would achieve the same points for sustainability according to LEED 2009 although their sustainability performance might be completely different. Although in the LEED 2009, a newly defined category named "Regional Priority" was introduced to address this issue [47], this has a minor impact on the performance results due to (1) the optional category of "Regional Priority" in LEED and (2) allocation of small point (i.e. only accounted for 4 bonus points compared to the total 100 sustainability points). This demands a more effective method to incorporate climatic differences in GBATs.

The sustainability performance of LEED relative to climatic factors have been investigated by some studies in recent years. Cidell and Beata (2009) investigated "spatial variation among building certification categories" of the LEED for different states in the US [35]. Boschmann and Gabriel (2013) studies the lack of a deep green design approach that focuses on local geographic conditions in the LEED credits [48]. Cheng and Ma (2015) used data mining techniques to investigate the relationship between climate factors and LEED credit achievements [45]. Wu et al. (2017) also conducted research to analyse credit achievement patterns and regional variation of credit attained by LEED 2009 certified green buildings on a country level [36].

In order to conceive climatic differences properly, one efficient pragmatic solution is to group regions based on similar climates. The relatively large number of meteorological variables, which affect climatic categorisation, has led researchers to use clustering methods [45]. Various clustering methods such as *K*-means, *k*-median and support vector machine (SVM) have been widely used for climatic clustering [49, 50].

Although a plethora of research works have been used in the above-reviewed literature for customising the GBATs, to the best of authors' knowledge, none of them has considered clustering methods for GBATs customisation based on the climatic factors. Hence, this paper aims to develop a framework for customisation of GBATs based on climatic parameters and experts' judgement by using fuzzy AHP and *K*-means methods for a country with different climatic regions and local sustainability priorities. Fuzzy-AHP is used here as a decision-making method for customisation of GBATs, due to the subjective nature of green building indicators. The *K*-means is also used here for climatic clustering among these various methods due to its merits over other methods e.g. relatively simple approach to create, easily adapted to new datasets and guarantee for the convergence of clusters [51]. The proposed framework is also demonstrated by its application to the case study of Iran as a country with various climatic regions. *K*-means method is used here for climatic clustering based on the climatic data collected from more than 80 cities in Iran. This study also selects "LEED EB 2009" as a well-known GBAT for modification of indicators and the related weights in different regions. Details of the methodology is presented in the next section followed by introducing the case study and presenting the results and discussion.

2. Methodology

Fig. 1 shows the framework proposed in this study in four steps for climatic customisation of GBATs and sustainability priorities in developing countries. The first step entails collecting and identifying climatic factors with major impacts on the sustainability performance of buildings throughout their whole life cycle. This step is carried out by undertaking a desktop study and Delphi method. The second step makes use of the *K*-means clustering method to selected regions and cities based on the derived climatic factors. This may result in several diverse climatic zones and consequently, makes the process of customisation of the GBAT's categories and criteria precise in each climatic zone. In the third step, Delphi method is used again to incorporate experts' judgements for primary customisation of categories and criteria of the GBAT (LEED EB 2009 is used in this study) based on the sustainability priorities of the pilot country. The fourth step applies the fuzzy analytical hierarchy process (FAHP) method to determine the final weights and scores of categories and criteria in each region (final customisation). A number of experts participate to give their judgement for weighting the climatic factors in the FAHP process. The experts' judgements can be applied either evenly (i.e. equal weights for their opinions) or with weighs that are determined based on their relevant experience, educational level, and job position. More details of these steps are described in the following sections.

2.1. Related climatic factors for sustainability performance of buildings

This step collects several climatic factors from literature, followed by a screening process by a panel of experts using the Delphi method as a systematic and interactive tool. Hence, a literature review is first conducted to identify the main climatic parameters that have major impact on the sustainability performance of buildings [13,36,45,52–57]. There are some local limitations such as the various local climates, availability of data, and local construction methods and materials which need to be considered to specify effective climatic parameters. Hence, assistance of local experts is required to overcome these limitations and finalise the most important parameters. The Delphi method is used here to provide a well-structured process of obtaining and extracting knowledge from a group of experts by incorporating several rounds of feedback [58,59].

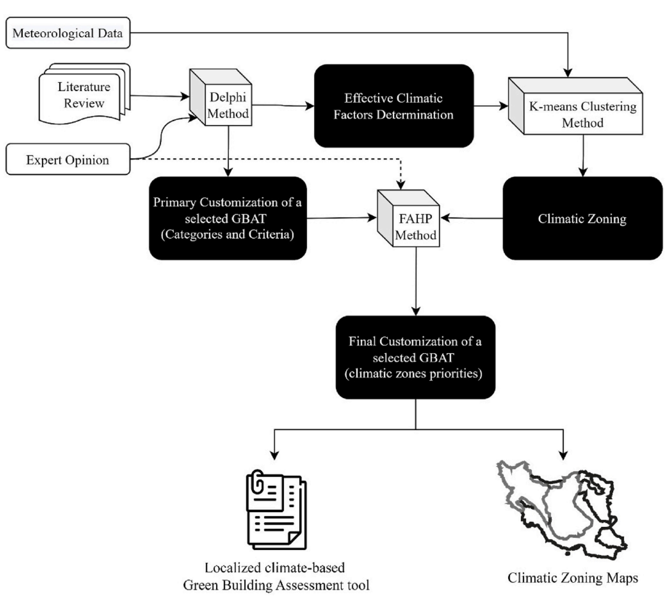

Fig. 1. The proposed framework for climate-based customisation of green buildings assessment tools.

More specifically, the experts are involved in filling out questionnaires in several rounds. A moderator provides an anonymised summary of the experts' answers with their reasoning after each round. Experts are then encouraged to update their previous answers by considering other members' responses. The number of the respondents filling the questionnaires out may decrease within the following rounds [23,60].

2.2. Climatic zoning

This step divides cities of the country into several zones based on climatic characteristics determined in the previous step. *K*-means clustering method is used in this study for climatic zoning due to its simplicity, high accuracy, and its broad application in meteorological purposes [61,62]. *K*-means assigns objects to their closest cluster centre according to the Euclidean distance function. More specifically, it calculates the centroid or arithmetic mean of all objects in each cluster. These steps are repeated until the same points are assigned to each cluster in consecutive rounds. Different approaches can be used to perform the initial stage and the convergence condition of the *K*-means method. In this study, Lloyd's algorithm is applied due to its higher convergence compared to other algorithms [63]. The Lloyd's algorithm is conducted in the following four stages:

1 Randomly specifying the centres of the clusters ($\mu_i^{(0)} = \mu_1^{(0)}, \mu_2^{(0)}, \mu_3^{(0)}, ..\mu_i^{(0)} = \mu_1^{(0)}, \mu_2^{(0)}, \mu_3^{(0)}, ...$)

The following two stages are then repeated until the means converge or the total variance of the clusters has no significant change.

2 $S_i^{(t)} = \{x_P : \left\|x_P - \mu_i^{(t)}\right\|^2 \leq \left\|x_P - \mu_i^{(t)}\right\|^2 and \forall j, 1 \leq j \leq k\}$ (1)

where $S_i^{(t)}$ is cluster *i* at time *t*, x_P includes all points at the initial cluster, and *k* is the number of clusters.

3 All clusters are updated based on the equation below:

$$\mu_i^{(t+1)} = \frac{1}{S_i^{(t)}} \sum_{x_j \in S_i^{(t)}} X_j \mu_i^{(t+1)} = \frac{1}{S_i^{(t)}} \sum_{x_j \in S_i^{(t)}} X_j \tag{2}$$

4 Finally, $\mu_i^{(T)} = \mu_1^{(T)}, \mu_2^{(T)}, \mu_3^{(T)}, ...$ are obtained as the final representatives of clusters.

The *K*-means method is calculated here in MATLAB 2020 software. As the *K*-means method is an unsupervised clustering procedure, the initial number of the clusters (*k*) for climatic zoning is basically defined by the user. There are several methods which suggest the optimum number of clusters. Here, the term "optimum number" stands for a number of clusters in which the members of each cluster have the most similarities with each other and the most dissimilarity with members of other clusters. One flexible and widely used methods for validity assessment of clusters is the silhouette method [64], which entails two clustering factors: separation (i.e., average distance to the closest other cluster) and compactness (i.e., average within-cluster distance) [65]. The Silhouette value method used in this study can provide the optimal number of climatic zones. The silhouette value for each point is measured by its affiliation to the related cluster compared to the adjacent clusters. The silhouette value varies from −1 to +1, where a high value indicates that a member is well harmonised to its cluster and defectively suited to adjacent clusters. A well-suited clustering configuration is reached when most of the points gain high Silhouette values. Otherwise, the clustering arrangement may have too many or too few clusters. Silhouette value can be calculated as [66]:

$$S_i = \frac{b_i - a_i}{max\{a_i, b_i\}}, if|C_i > 1| \tag{3}$$

where C_i is cluster i between 1 and n i.e. $C_1, C_2, C_3, ..., C_n$; a_i and b_i illustrate the average distance of one point from other points in the same cluster and minimum average point distance with other clusters, respectively. Moreover $a_i$and b_i can be calculated as:

$$a_i = \frac{1}{|C_i| - 1} \sum_{l=1}^{n_i} d(X_i, X_l) \tag{4}$$

where $d(X_i, X_l)$ is the distance between point i and l, n_i is the number of all points in the particular cluster (C_i),

$$b_i = min \frac{1}{|C_k|} \sum_{j \in C_k}^{n_i} d(i, j) \tag{5}$$

where C_k is another cluster than $C_i$and $d(i,j)$ is the distance between point i which belongs to cluster i and point j from C_k.

Once applying the *K*-means method for various numbers of clusters, the optimal number of climatic zones can be associated with the one corresponding with the highest Silhouette value among all clustering numbers. Having said this, a visual assessment of a few clustering numbers with high Silhouette values can validate if the clustering number associated with the highest Silhouette value is appropriate according to other norms of climatic divisions in the case study. After selecting the optimal clustering number, each city is placed in one of the climatic zones and thus the parameters of the buildings' sustainability performance can be prioritised accurately in the next steps.

2.3. Primary customisation of a selected GBAT (category and criteria)

The desired customised GBAT is obtained based on categories and criteria of the existing GBATs and the local experts' opinions. In this study, LEED EB 2009 is used as a benchmark, due to its high popularity among sustainable building experts in developing countries [21]. In order to modify the categories and criteria of LEED EB 2009, experts' judgement is combined using the Delphi method through conducting a number of interviews with local experts to determine the localised categories and criteria.

2.4. Final customisation of the GBAT

The weights of categories and criteria are obtained in this step based on the experts' judgements and the FAHP method. The required steps are described in detail below.

2.4.1. Selection and evaluation of experts

First step is to select some experts to fill out designed questionnaires. To gain reliable results, the experts should have sufficient experience and expertise in the field of sustainable buildings. Hence, it is recommended that stakeholders are selected from related jobs and organisations such as the construction industry, urban planning organisations, environmental organisations, and university professors [21,67]. To determine the right number of experts, the sample size is recommended to be large enough that the responses' patterns are clearly visible. In the present study, there are certain complexities when completing the sustainability-type questionnaires, such as the need for a multi-aspect point of view. Hence, it is better the questionnaires are completed by participants whose responses are less inconsistent and more reliable. Furthermore, relevant researches recently carried out suggest a range of between 30 and 103 participants would be appropriate for a reliable study [8,19,68–72]. The suggested maximum number can be linked to avoiding inconsistency of the responses. After selecting the experts, the questionnaires can be filled out, the responses are obtained for each climate obtained in step 2-2. The weights of the categories and criteria in each climate are specified by applying the FAHP model that is described in the next section.

2.4.2. FAHP method

The FAHP is processed here within three main stages (1) setting an assessment hierarchy; (2) assigning linguistic variables; (3) analysing the questionnaire. These stages are described in the following.

2.4.2.1. Analytical hierarchy setup. The analytical hierarchy is first structured as shown in Fig. 2 in three hierarchical levels as the main goal, categories and criteria. A set of questionnaires is then set out to identify the weights of each category and criterion based on two sets of pair-wise comparison questions. The questionnaires collect the preferability/priority of each category and criterion from the experts' perspective. The first set comprises questions for comparing and prioritising categories with respect to the main goal for each climatic zone. The second set entails the same comparison for prioritising criteria with respect to each category.

2.4.2.2. Linguistic terms. The above pairwise comparisons are drawn by experts through linguistic terms describing the level importance of each category and criterion. These linguistic terms are defined as a set of words or sentences that are inherently subjective and can be linked to fuzzy numbers in the FAHP. Pairwise comparisons used in the questionnaires of this study are conducted by employing nine linguistic terms with associated fuzzy numbers shown in Table 2 as "Perfect", "Absolute", "Very Good", "Fairly Good", "Good", "Preferable", "Not Bad", "Weak Advantage", and "Equal". This study applies the calculation method introduced by Gumus to combine the relevant fuzzy numbers [73]. Membership functions used here are defined by the symmetric triangular fuzzy number (TFN) including three parameters (left point, middle point, and right point) for each function.

2.4.2.3. Questionnaire analyse. The questionnaires filled out by experts are analysed within the following steps.

2.4.2.3.1. Fuzzy synthetic extend value of rows. When the linguistic variables are assigned by experts for each pair-wise comparison, the FAHP steps are conducted based on Chang's extend method [74] as follows:

The first step is the pairwise comparison of questionnaire for fuzzy synthetic extend value, to specify the relative importance of each pair of categories/criteria (S_i) from a set of triangular fuzzy numbers as below:

$$S_i = \sum_{j=1}^{m} M_{gi}^j \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j \right]^{-1} \tag{8}$$

where i is the row of matrices and j represents the column number. The values of $\sum_{j=1}^{m} M_{gi}^j$, and $[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j]^{-1}$ are determined by Eqs. (9) and (10), respectively.

$$\sum_{j=1}^{m} M_{gi}^j = \left(\sum_{j=1}^{m} l_{ij}, \sum_{j=1}^{m} m_{ij}, \sum_{j=1}^{m} u_{ij} \right) = (l_l^{'}, m_l^{'}, u_l^{'}) \tag{9}$$

$$\left(\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j \right)^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_l^{'}}, \frac{1}{\sum_{i=1}^{n} m_l^{'}}, \frac{1}{\sum_{i=1}^{n} l_l^{'}} \right) \tag{10}$$

2.4.2.3.2. Calculation of possibility degree between two TFNs. The second step estimates the possibility degree between the two TFNs as illustrated in Fig. 3. For fuzzy numbers of $S_1 = (l_1, m_1, u_1)$ and $S_2 = (l_2, m_2, u_2)$, possibility degree V (S1 ≥ S2), is calculated as:

$$V(S_1 \geq S_2) = highest\ (S_1 \cap S_2) = \mu_{S_1}(d)$$

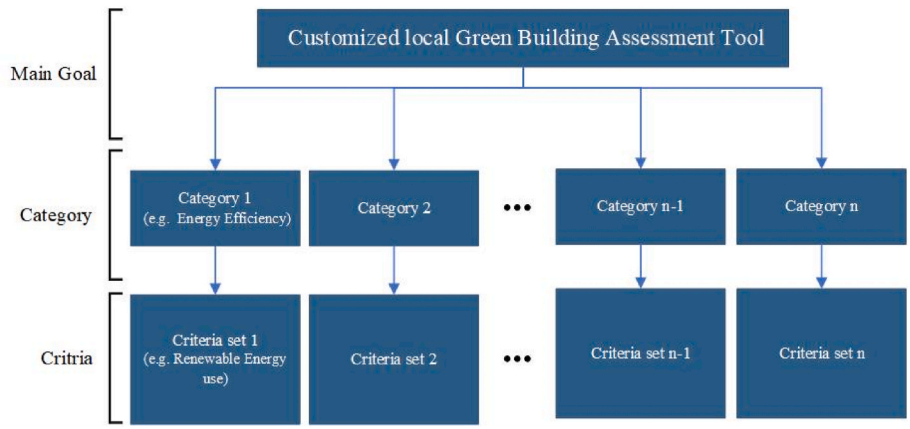

Fig. 2. The analytical hierarchy process for customising green buildings assessment tools. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 2
Linguistic terms with associated fuzzy membership numbers.

Number	Linguistic term	Fuzzy number
9	Perfect	(8,9,10)
8	Absolute	(7,8,9)
7	Very Good	(6,7,8)
6	Fairly Good	(5,6,7)
5	Good	(4,5,6)
4	Preferable	(3,4,5)
3	Not bad	(2,3,4)
2	Weak Advantage	(1,2,3)
1	Equal	(1,1,1)

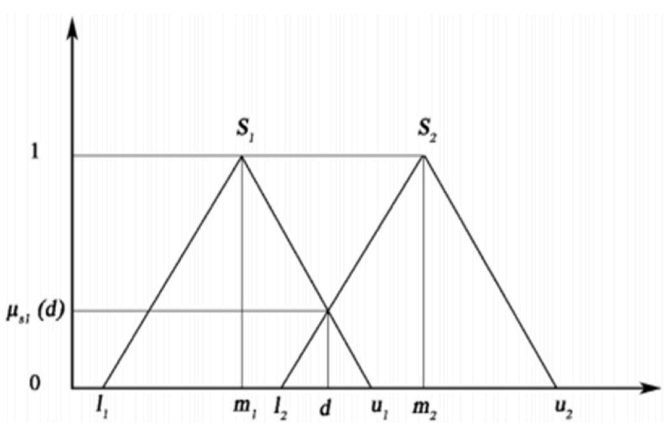

Fig. 3. Possibility degree between fuzzy numbers S_1 and S_2.

$$\mu_{S_1}(d) = \begin{cases} 1 \quad if\ (m_1 \geq m_2) \\ 0 \quad if (l_2 \geq l_1) \\ \dfrac{l_2 - u_1}{(m_1 - u_1) - (m_2 - l_2)} \quad otherwise \end{cases} \tag{11}$$

where d is the ordinate of the highest intersecting point between μ_{S_1} and μ_{S_2}.

2.4.2.3.3. Degree of possibility for convex fuzzy number. The third step includes obtaining the degree of possibility for convex fuzzy number which is greater than k convex fuzzy numbers S_i; $i = 1, 2, \ldots, k$ as below:

$$V(S \geq S_1, S_2, \ldots, S_k) = V((S \geq S_1), (S \geq S_2), \ldots, (S \geq S_k)) =$$

$$Min(V(S \geq S_1), (S \geq S_2), \ldots, (S \geq S_k)) = Min(V(S \geq S_i) \tag{12}$$

2.4.2.3.4. Normalised final weight vectors. The fourth step calculates the normalised final weight vectors for each individual category as:

$$W = (d(A), d(A_2), \ldots, d(A_n))^T \tag{13}$$

where W is a regular number and a local normalised weight comparable with other priority weights calculated for categories and criteria. These weights are then used in the next step to calculate the final score of criteria.

2.4.2.3.5. Final scores of criteria. The fifth step calculates the final score of each criterion by multiplying its weight by the weight of associated category and 100. The final scores were rounded to form integer numbers. Multiplication of the number "100" is due to the use of LEED scoring system in this study, which allocates scores between 0 and 100 in order to rate buildings' performance. Hence, the final criteria score can be calculated as:

$$\text{Final categories score} = W_n \times 100 \tag{14}$$

$$\text{Final criteria score} = W_n \times W_m \times 100 \tag{15}$$

where W_n and W_m are the relative weight of category n and criterion m, respectively. The final scores were rounded up to form integer numbers.

2.4.2.3.6. Result validation. The level of inconsistency of the pairwise comparison for each expert needs to be calculated based the consistency ratio (CR) obtained based on the random consistency index (RI) [75] as:

$$CI = (\lambda_{max} - n) / (n - 1) \tag{16}$$

$$CR = CI/RI \tag{17}$$

where λ_{max} is the maximum eigenvalue which is calculated by multiplying the priority vector weights by the judgments' values. Both quantities are derived from the response matrixes; n is the number of alternatives (options) in every response matrix. Matrix compatibility is only accepted when the consistency ratio CR is less than 0.1 ($CR < 0.1$). Otherwise, the response matrix (i.e. questionnaire) should be revised by the experts until fulfilling the above condition.

2.4.2.3.7. Standard deviation of weights. To investigate the effects of various climates on experts' judgements, the standard deviation of the weights identified for categories/criteria in each zone (cluster) is calculated as:

$$\sigma = \sqrt{\frac{\sum (w_i - \mu)^2}{N}} \tag{18}$$

where σ = standard deviation; w_i = the final weight of category/criterion i in each climate zone; N = the number of clusters; μ = the average weight of categories or criteria. The more the standard deviation, the more a category/criterion is affected by climate zones through experts' judgement.

3. Case study

The above methodology is demonstrated here by the application of LEED EB 2009 as a well-known green building assessment tool to provide a customised tool suitable for the case study in Iran with various climates in the country. Iran has a total area of about 1.65 million km^2, more than half of which is covered by deserts and mountains, and almost 16% has an altitude of more than 2000 m above the sea level. Scorching summers in many parts of the country with high temperatures up to a record of over 55 °C in some places during summers are the key climatic features in Iran [76]. Due to the high altitude and the continental condition of the country, cold winters with low temperatures (minus 20 °C is commonplace) are other key attributes of the climate in Iran. Annual precipitation also varies widely in different regions, ranging from 50 mm to 1600 mm, with an average of 252 mm. In addition, almost 90% of the country is located in arid or semiarid regions. Therefore, geographic location and the varied topography of Iran has led to a diverse climate [77].

Although various methods of climatic zoning for buildings were developed in Iran, they only group clustering on regions for energy efficiency improvement [78]. These regions do not necessarily consider climate-related sustainability priorities e.g., water efficiency and hence, current climate zoning methods cannot be used for development or customisation of green building assessment tools. Some examples of these activities in Iran include an official handbook called "climatic zoning of Iran for houses and residential environments" published by the Ministry of Housing and Urban Development in 1992 to tackle energy efficiency issues. A set of regulations were also derived by the same Ministry to improve energy efficiency in different cities considering climatic differences in 2009 [79]. This suggests a need for a new climate zoning approach in which regions and cities - with the most similarity in term of sustainability priorities (water efficiency, energy efficiency, material use, etc.) - can be grouped together as a climatic zone. This will allow a GBAT (in this case LEED EB 2009 in Iran) to adopt specific set of measures in each zone to promote sustainability in building sector based on common climatic characteristics.

4. Results and discussion

4.1. Related climatic factors for sustainability performance of buildings

Based on the literature review of potential climatic parameters that have an effect on sustainability performance of a building, an initial set of climatic parameters were identified as shown in Table 3.

The most important and related climatic parameters to buildings' sustainability performance were selected from the parameters given in Table 3 based on the Delphi method by involving a group of 9 local experts specialised in urban geography, urban development, architecture, and environmental engineering. After two rounds of correspondence and collection of feedback using the Delphi method, the number of selected climatic parameters were decreased to 7 and then 4 parameters. The set of 7 parameters were (1) mean precipitation (MP), (2) standard deviation of monthly mean precipitation (MP_sd), (3) standard deviation of monthly mean temperature (Temp_Sd), (4) mean diurnal temperature range (DTR), (5) standard deviation of monthly mean diurnal temperature range (DTR_Sd), (6) cooling degree days (CDD), and (7) heating degree days (HDD). Out of these seven parameters, the four final selected parameters were MP, DTR, HDD, and CDD. While having discussion about the reasons behind this selection, the main arguments made by this group of experts are as follows.

Firstly, as the number of selected dimensions (parameters) increases, the quality of clustering declines [80]. In other words, considering a

Table 3
Initial set of climatic parameters.

No	Initially-selected set of climatic parameters	Unit	Abbreviation
1	Mean temperature	°C	Temp
2	Mean diurnal temperature range	°C	DTR
3	Heating degree day	°C	HDD
4	Cooling degree day	°C	CDD
5	Mean precipitation	mm	MP
6	Mean snowfall	mm	Snow
7	Number of days with precipitation more than 0.001 inches	day	MP_D
8	Number of days with snowfall more than 0.01 inches	day	Snow_D
9	Number of cloudy days	day	Cloudy_D
10	Number of Partly Cloudy Days	day	Pcloudy_D
11	Number of clear days	day	Clear_D
12	Average daily humidity	%	Hum
13	Percentage of humidity in the morning	%	Hum_am
14	Percentage of humidity in the afternoon	%	Hum_pm
15	Percentage of sunshine	%	Sun
16	Average daily wind speed	Km/hr	Wind
17	Standard deviation of monthly mean temperature	°C	Temp_Sd
18	Mean annual temperature range	°C	Temp_R
19	Standard Deviation of Monthly Mean Precipitation	mm	MP_Sd
20	Standard deviation of monthly mean diurnal temperature range	°C	DTR_Sd
21	The difference of humidity in the morning and in the afternoon	%	Hum_diff

large set of climatic parameters can potentially result in unacceptable clustering in the next step and hence a limited number of parameters are more preferred. Secondly, it can be argued that the selected parameters implicitly encompass others to a large degree. In other words, almost all other unselected climatic parameters have either a direct or indirect relationship or at least a correlation with the selected ones such as the relationship between wind and precipitation [81,82] or the relationship between solar radiation and diurnal temperature range (DTR) [83–88]. For example, only DTR parameter is selected in this study that can be a surrogate for solar radiation. Finally, since the proposed climate zoning is a basis for a locally customised green building assessment tool, further climate considerations can be made in the primary and final customisation steps. In other words, by customising the categories and criteria themselves and also by assigning more or less weight to some specific categories and criteria, other possible neglected climatic factors can be taken into consideration.

The selected four climatic parameters were calculated based on the following principles and assumptions. MP is the average total amount of rainfall recorded throughout a year in a specific location extracted from online, free-access data bases or official records. DTR is the variation of temperature between the maximum and minimum daily amount calculated from time series of hourly temperature. CDD and HDD are parameters describing the temperature of a location during a fixed period of time and compare the average of daily maximum and minimum temperatures of a location to a predetermined base temperature that is 18 °C for HDD and 24 °C for CDD recommended by the Ministry of Transportation and Urban development in Iran [89]. The two most commonly used methodologies for calculation of CDD and HDD are [90]: (i) American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) daily mean temperature method [91]; and (ii) United Kingdom Met Office (UKMO) method [92]. Annual CDD and HDD were calculated in this study according to ASHRAE method using Eqs. (19) and (20), respectively as below:

$$\mathrm{HDD18^{\circ}C} = \sum_{i=1}^{365} [(\mathrm{T_b} - \mathrm{T_d})]^{+} \tag{19}$$

$$\mathrm{CDD24^{\circ}C} = \sum_{i=1}^{365} [(\mathrm{T_d} - \mathrm{T_b})]^{+} \tag{20}$$

where the daily degree-days are the difference between the daily mean temperature (T_d) and base temperature (T_b). The sign (+) indicates that it is only necessary to calculate positive differences. T_d is also calculated using Eq. (21).

$$T_d = \frac{(T_{max} - T_{min})}{2} \tag{21}$$

The climatic data was collected for 93 available meteorological stations between 2010 and 2020. Out of these stations, 13 stations were removed from the analysis because they were considered unreliable due to having significant missing data. The values of MP, DTR, CDD, and HDD were then calculated for the remaining stations. The distribution of these stations is shown in Fig. 4.

4.2. Climatic zoning

The four climatic parameters for the 80 meteorological stations were clustered using the *K*-means method. The silhouette value (SV) was used to find the optimum number of clusters. Hence, the SV was calculated for a range of *k* numbers between 3 and 8, i.e., 6 runs of the clustering with the *K*-means method, each to calculate a unique SV for a specific *k* number. Table 4 shows the silhouette values associated with different numbers of clusters. As can be seen, the highest values of SV, indicating the best clustering quality were obtained for 4, 3, and 5 clusters, respectively. Hence, this indicates the number of four clusters is the best number of climatic clusters for sustainability performance of buildings in Iran.

To further validate the optimal number of climatic zones, zoning maps for the three zone numbers i.e. 3, 4, and 5 clusters are compared in Fig. 5 along with radar charts representing the normalised values of meteorological parameters (MP, DTR, CDD, and HDD) for each zoning map. Comparing different zones and parameters in Fig. 5I shows the three normalised values of CDD, HDD, and MP of the clusters can be clearly distinguished. However, the zoning map shows some relative inconsistency between specified zones and their climatic parameters. For example, mean annual precipitation in zone 3c is highly variable ranging from 220 to 1330 mm. On the other hand, the weak point for the 5-cluster zoning map in Fig. 5.III is the division of some regions with similar climatic features into different zones. Hence, the radar chart of Fig. 5.III for zones 5b and 5d is quite identical for some climatic parameters such as CDD, precipitation, and HDD. However, there is no specific issue present in the 4-cluster zoning map (Fig. 5.II) and therefore not only the four entirely distinct zones are identified in the radar chart, but also there is a consistency between climatic zones in the 4-cluster zoning map.

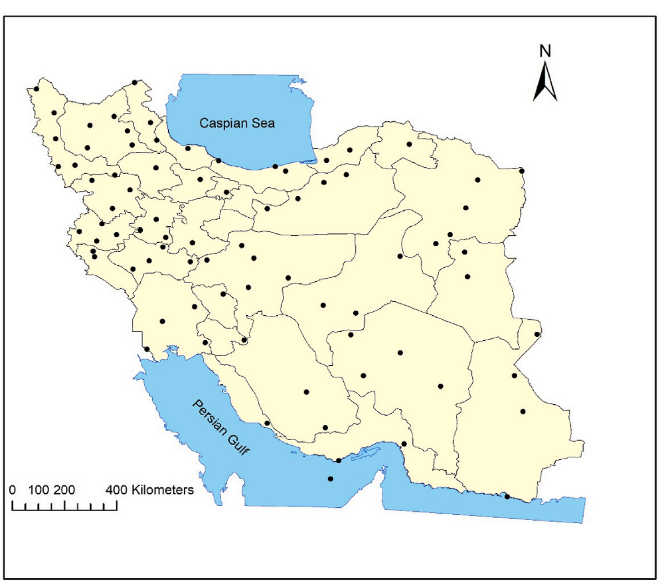

Fig. 4. Distribution of weather stations used in this study.

Table 4
The Silhouette value for different numbers of clusters in the *K*-means method.

Number of clusters (zones)	3	4	5	6	7	8
Silhouette value (SV)	0.39	0.46	0.32	0.28	0.25	0.20

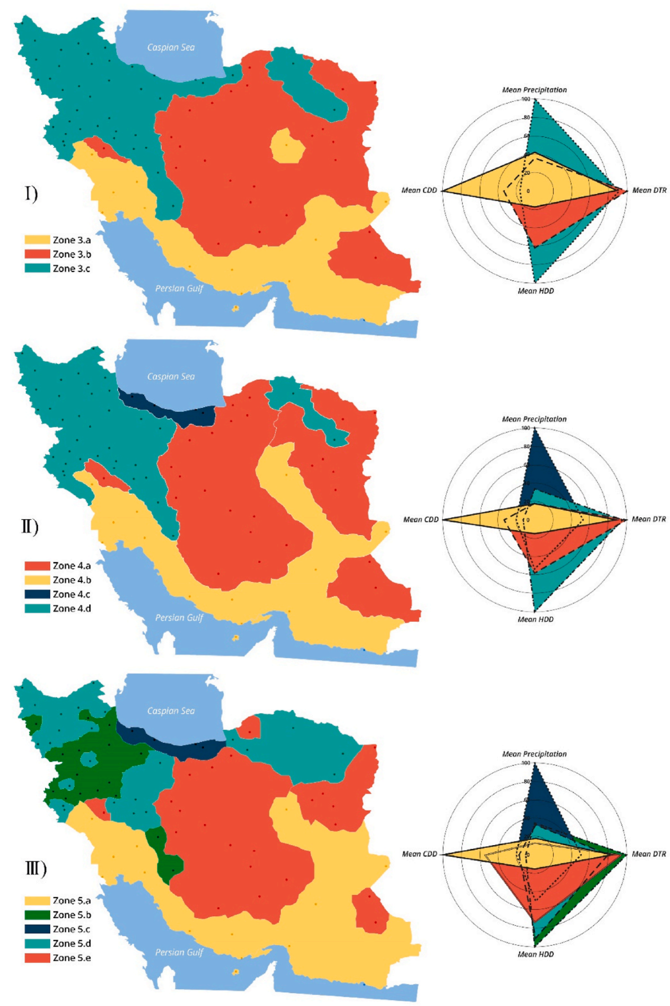

Fig. 5. Climatic zoning maps in the case study for (I) 3 clusters, (II) 4 clusters and (III) 5 clusters.

Table 5 shows the mean value of the four climatic parameters in each of the four climatic zones shown in Fig. 5.II. Although the MP values in zones 4a and 4b are in close proximity, other three climatic parameters especially HDD and CDD are quite distinct from each other. In addition, zone 4c has unique figures of the high MP and low DTR values compared to zone 4d with the high HDD value.

Table 5
The mean value of the four main climatic parameters in each of the four climatic zones.

Zone number	MP (mm)	DTR (C^o)	HDD (C^o)	CDD (C^o)
Zone 4a	193.3	14.4	1329.5	568.3
Zone 4b	190.2	12.8	344.6	1761.6
Zone 4c	1075.4	7.5	1226.1	353.3
Zone 4d	363.1	13.8	2293.5	219.3

4.3. Primary customisation (categories and criteria) of the selected GBAT

Following the climatic division in Iran, another Delphi survey was conducted to customise the categories and criteria suggested by the LEED EB 2009 as the benchmark (primary customisation of a selected GBAT). This Delphi survey was conducted through a number of questionnaires filled out by 7 experts in the field of green buildings, local geography, and project management. As a result, a total of 6 categories and 24 criteria were selected by experts within two rounds of correspondence. Fig. 6 shows the final list of categories and criteria selected for the sustainability assessment of the GBAT. As a result, out of 6 categories, "Sustainable Sites" with 7 criteria and "Energy and Atmosphere" with 6 criteria have the highest number of criteria.

4.4. Final customisation (climatic zones priorities) of the selected GBAT

To calculate the weight of categories and criteria, the experts involved in relevant organisations and professional bodies were first asked to fill out the relevant questionnaire based on linguistic terms. As a result, 68 responses were received from experts for screening and consistency assessment. This led to 56 qualified questionnaires based on the consistency ratio (CR) less than 0.1 [93]. These qualified questionnaires comprise 37.5% from the construction industry, 26.8% from municipal organisations, 23.2% from the environmental organisations and 12.5% from the university professors. Table 6 shows the distribution of the fields of expertise, job position, educational level and professional experience of the participants in the questionnaire. As can be seen, a good range of experts with different levels of education, experience and role were involved in the questionnaire. Note that assigning weights to each expert based on their experience, educational level and role can have some merits in scientific context and has been used in several research works [94]. However, such a weighting scheme can be ethically or even technically controversial and may raise critical questions about the fairness of judgement and social acceptance. Hence, the analysis and results in this study assumes equal weights for the comments of all experts participated in the questionnaire.

As per comparison of the criteria with respect to each category for each climatic zone, the combined judgments of experts were calculated and integrated by using Eq. (11). A detailed summary of these calculations for each climatic zone is provided in Appendix B. Eq. (13) was then used to convert the obtained fuzzy numbers into normalised final weights (W) of categories and criteria. Finally, the final scores of the categories and criteria were specified by using Eqs. (14) and (15). Table 7 gives a summary of the scores of categories and criteria for each climatic zone obtained from Eqs. (13)–(15). As can be seen, the sum of scores for either categories or criteria is 100 for each climatic zone.

Table 6
Fields of expertise, educational level and professional experience of the 56 experts participated in the questionnaire.

Expertise type	Expertise description	Number of participants
Job position	High-level decision maker (managers in construction and municipal organisations)	3
	Middle-level decision maker (supervisors in state municipal organisations)	5
	Low-level decision maker (project managers)	9
	Consultant	9
	University board	4
	Architects and engineers	8
	Contractors	10
	Board of trustees	8
Educational level	Diploma or experimental degrees	9
	BSc	20
	MSc	15
	PhD	12
Professional experience	<15 years	21
	>15 years	35

To further investigate the results, the categories' weighting percentage of the customised GBAT in the four specified climatic zones is compared with those in LEED EB 2009 (the selected benchmark) in Fig. 7. As can be seen, the average weight of the "water efficiency (WE)" category in four climatic zones is almost doubled (around 25%) compared to LEED's one. This figure for the "materials and resources (MR)" category is 14.25%, showing a more than 4% increase compared to LEED's. Allocating considerable weight to WE in Iran can be due to various reasons, such as the lack of adequate surface and ground water resources, high cost of drinking water treatment, and high urban water consumption in Iran [95]. The higher relative weight of MR could be interpreted as the need for sustainable use of materials and resources in Iran.

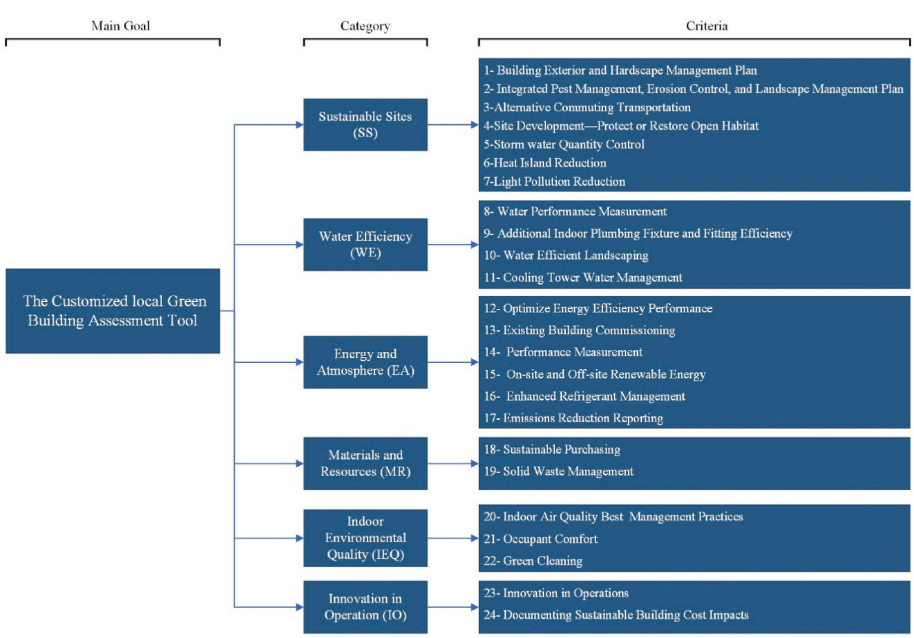

Fig. 6. Categories and criteria selected for the sustainability assessment of buildings.

Table 7
Weights (scores) of categories and criteria for each climate in the customised GBAT.

Category	Category score ($W_n \times 100$)				Criteria number	Relative criteria weight (W_m)				Criteria score ($W_n \times W_m \times 100$)			
	Zone 4a	Zone 4b	Zone 4c	Zone 4d		Zone 4a	Zone 4b	Zone 4c	Zone 4d	Zone 4a	Zone 4b	Zone 4c	Zone 4d
Sustainable Sites	13	14	24	18	(1)	0.092	0.156	0.176	0.182	1	2	4	3
					(2)	0.122	0.059	0.163	0.170	2	1	4	3
					(3)	0.336	0.193	0.218	0.165	4	3	5	3
					(4)	0.076	0.104	0.205	0.108	1	1	5	2
					(5)	0.206	0.141	0.075	0.290	3	2	2	5
					(6)	0.099	0.200	0.084	0.045	1	3	2	1
					(7)	0.069	0.148	0.079	0.040	1	2	2	1
Water efficiency	32	27	19	23	(8)	0.101	0.070	0.130	0.068	3	2	2	2
					(9)	0.351	0.343	0.373	0.393	11	9	7	9
					(10)	0.335	0.269	0.249	0.265	11	7	5	6
					(11)	0.212	0.317	0.249	0.274	7	9	5	6
Energy and Atmosphere	27	33	21	26	(12)	0.365	0.340	0.417	0.393	10	11	9	10
					(13)	0.177	0.217	0.252	0.218	5	7	5	6
					(14)	0.089	0.093	0.058	0.078	2	3	1	2
					(15)	0.107	0.111	0.078	0.082	3	4	2	2
					(16)	0.177	0.169	0.126	0.167	5	6	3	4
					(17)	0.085	0.069	0.068	0.062	2	2	1	2
Materials and Resources	12	9	19	17	(18)	0.437	0.333	0.381	0.413	5	3	7	7
					(19)	0.563	0.667	0.619	0.587	7	6	12	10
Indoor Environmental Quality	9	13	12	10	(20)	0.374	0.320	0.325	0.208	3	4	4	2
					(21)	0.440	0.516	0.236	0.436	4	7	3	4
					(22)	0.187	0.164	0.439	0.356	2	2	5	4
Innovation in Operations	7	4	5	6	(23)	0.722	0.707	0.679	0.650	5	3	3	4
					(24)	0.278	0.293	0.321	0.350	2	1	2	2
Σ	100	100	100	100	–	–	–	–	–	100	100	100	100

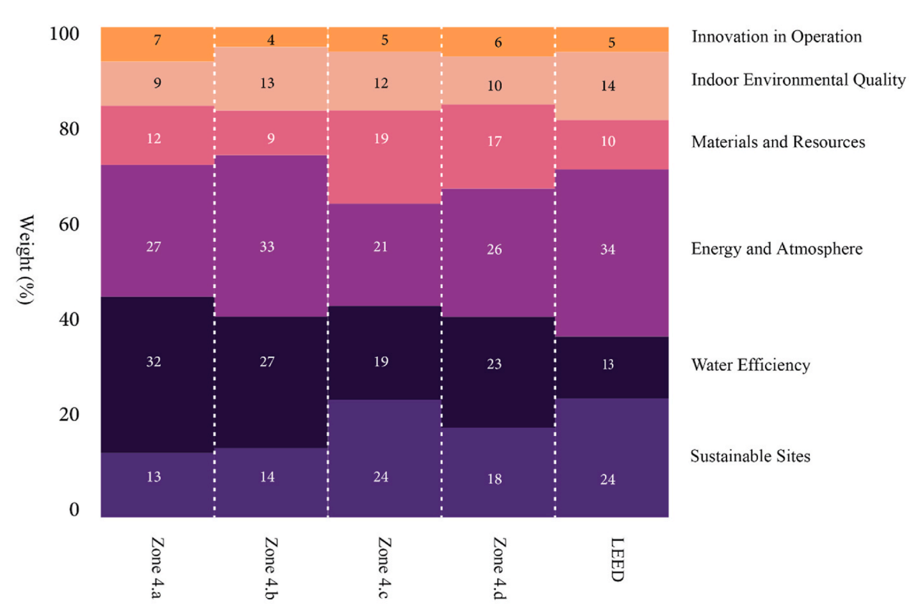

Fig. 7. Weighting percentage of the sustainability categories between four climatic zones of the present study and standard LEED EB 2009.

Other major differences are the reduction of the average weight of the "energy and atmosphere (EA)" and "sustainable sites (SS)" categories in the four climatic zones by almost 7% in comparison to LEED EB 2009. Although the emphasise on these two categories seems to be decreased in the customised GBAT, they still take a large share of the total weight by the average number of 26.75 and 17.25% for EA and SS, respectively. Furthermore, these figures in some zones are almost equals to those in the LEED EB 2009 (e.g., EA in the zone 4b and SS in the zone 4c). Furthermore, while the average weight of the "Indoor environmental quality (IEQ)" in the four climatic zones dropped to 11% in the customised GBAT, the figure for the "innovation in operation (IO)" category relatively remained the same (0.5% increase) compared to the selected benchmark. It could be argued that existing codes for construction and operation of building are sufficient to ensure the quality of the indoor environment and more emphasis on this category is unnecessary. In addition, similar weights for the "Innovation in Operation" category suggest the relatively consistent importance of this category compared to others in all conditions including the benchmark standard.

By looking closer into each climatic zone, the weight of each category can be better justified on the grounds of sustainability priorities in each zone. For example, "water efficiency" has the highest weight compared to the other categories in zone 4a. This can be due to certain climatic characteristics of this zone (i.e. hot and dry climate). Because of the wide range of diurnal temperature, increasing water demand, and lack of adequate water resources in this zone, relatively high importance of the "water efficiency" category can be justified. On the other hand, the "energy efficiency" category gained the most weight in zone 4b. This could be due to the challenging nature of providing thermal comfort in this climate (i.e., hot and humid) compared to other climates and consequently, there is more energy demand for air conditioning.

In most cities located in zone 4c (i.e., moderate and humid climate), the common key features of the climate include a high density of vegetative coverage, abundant sources of surface and groundwater, high population density, and moderate temperatures. These features in this zone can lead to allocating more weight to the "sustainable sites" category and less weight to the "Water Efficiency" and "Energy and Atmosphere" categories compared to other zones. In addition, the importance of solid waste management can be the main reason for the high weight of "materials and resources" category. Zone 4d is characterised as high altitude, relatively cold weather and moderate amounts of annual precipitation, and hence weights for all categories in this zone are close to the average. This can indicate that there are specific preferences and emphasise on any category by the experts for this zone compared to other zones.

As can be seen in Table 7, while the weight of some categories or criteria remained relatively the same in each climate, it changed significantly in some others. To investigate the effects of various climates on experts' judgements, the standard deviation of these judgements was calculated as shown in Figs. 8 and 9 for weights of categories and criteria, respectively. As can be seen in Fig. 8, the highest standard deviation (σ) of weights (the circle diameter) among categories was 4.82 related to the "Water Efficiency" category, followed by 4.32, 4.26, and 3.96 for the "Sustainable Sites", "Energy and Atmosphere", and "Materials and Resources" categories, respectively. This indicates these four categories can be more influenced by the climactic zones. On the contrary, the low standard deviations of weight allocated to the two remaining categories of "Indoor Environmental Quality" and "Innovation in Operation" shows they are less sensitive to climatic clustering. All this can provide a better insight into the categories that a GBAT should consider when analysing buildings under various climatic differences.

Furthermore, the standard deviation of the weights of criteria (the circles diameter) and their average weights in Fig. 9 show that the "Solid Waste Management" criterion had the highest standard deviation of weight (2.38), followed by 2.28, 1.66, and 1.64 for "Water Efficient Landscaping", "Sustainable Purchasing" and "Site Development". This indicates that these criteria can be highly affected by different climates. This highly variable indicators can be related to relatively major climatic differences for mean annual precipitation, diurnal temperature range and other related factors such as population density and vegetation coverage in the pilot study of Iran.

5. Conclusions

This paper presents the impact of climatic parameters on the performance of green building assessment tools. A customised weighting schemes was derived by for the assessment tool and a new customised green building assessment tool was developed for the well-known LEED EB assessment tool. This customisation was developed for sustainability categories and criteria of the tool based on the Delphi method, *K*-means clustering and fuzzy analytical hierarchy process. The hierarchy of the sustainability categories and criteria was first identified based on Delphi methodology and expert involvement. The climatic parameters were then used to divide the country case study into a several climatic zones by using *K*-means clustering technique and the silhouette value. The fuzzy AHP technique was then used to specify the new weights of sustainability categories and criteria for each climatic zones based on experts' judgements. According to the results presented, the following can be noted:

- Each climatic zone can obtain specific weights for sustainability categories and criteria based on the nature of its climate. For example, a zone with low annual rainfall, the water efficiency category has a higher weight while a zone with high heating or cooling needs, the energy efficiency category has a higher priority.
- Compared to the benchmarked GBAT (LEED EB 2009), the average weight of the water efficiency category increased significantly from 13% to about 25.25% in this case study due to the nature of limited water resources throughout the country.
- The index of current materials has also seen an increase of more than 4% compared to the benchmarked GBAT.

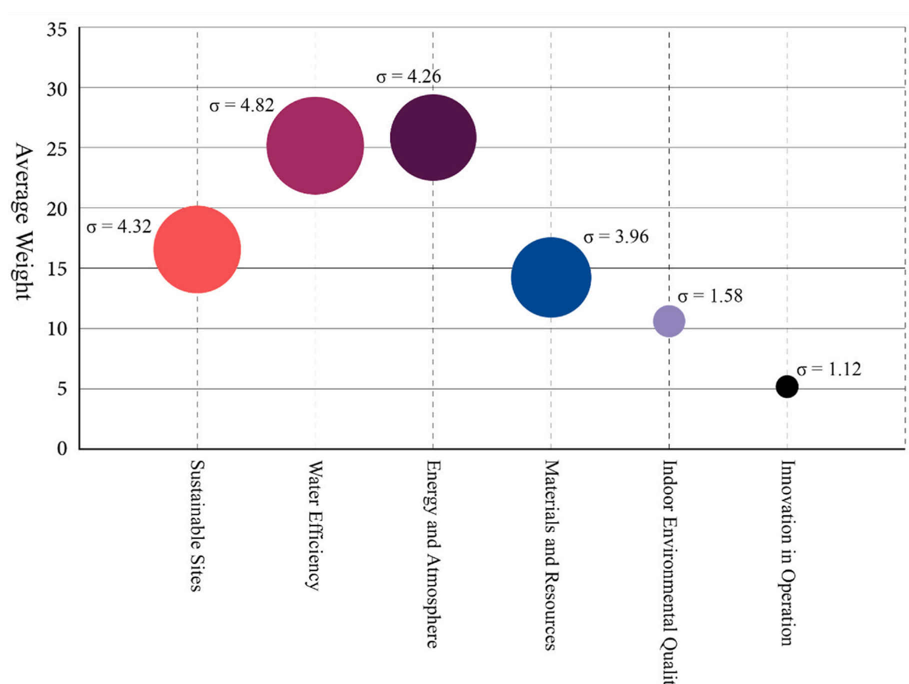

Fig. 8. Standard deviation of the weights for each category.

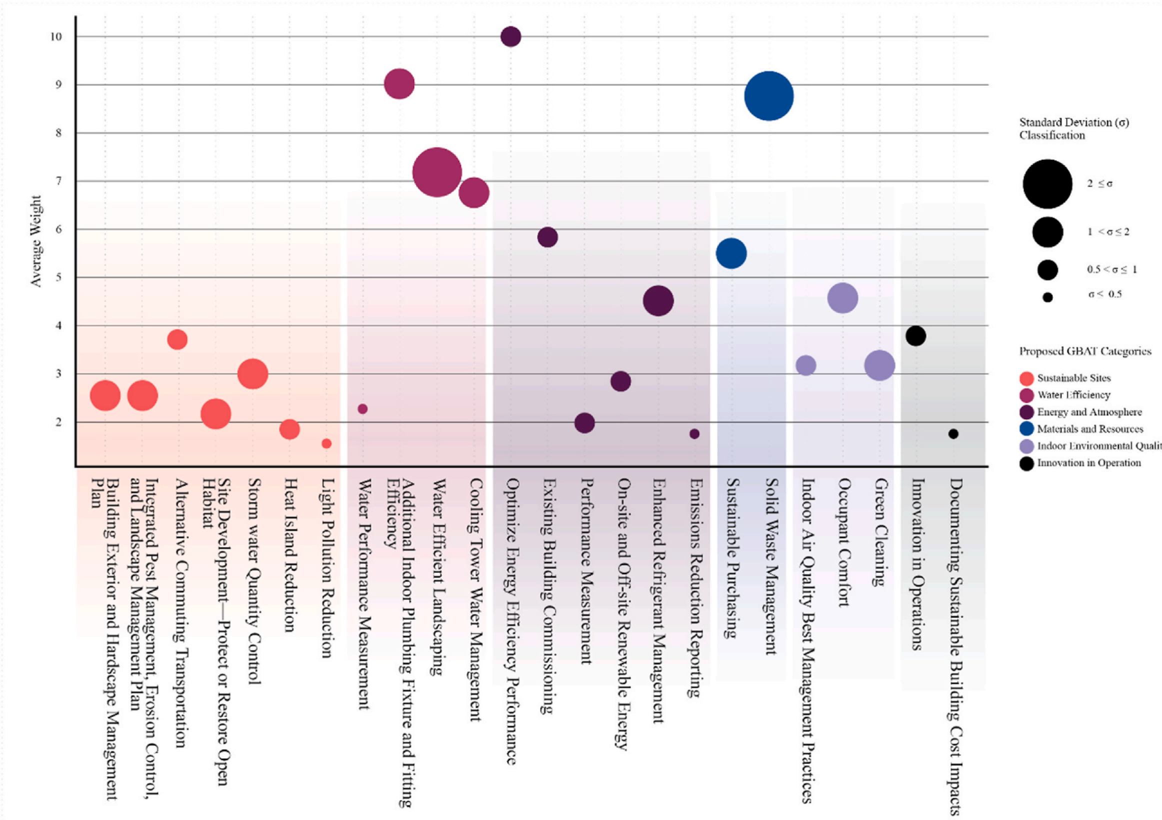

Fig. 9. Standard deviation of the weights for each criterion.

- The importance of the sustainable site category decreased from 24% in the principal regulations to 17.25%.
- The importance of other categories, such as energy efficiency, the quality of the internal environment, and innovation in exploitation, had minor changes compared to the benchmarked GBAT.

This study shows that a general assessment tool e.g. LEED EB 2009 may not be appropriate to be used for all regions of a country with diverse climate. Hence, the customisation of the assessment tools based on the climatic zone can be crucial due to the importance of raising some specific criteria in the areas that require improvement in the case study. This research mainly focused on the inclusion of climatic factors in the sustainability assessment of buildings. The scope of this research is limited to climatic characteristics and it can be concluded that the major meteorological differences between the four zones has led to various sustainability priorities identified by the experts. However, the impacts of other aspects of sustainability such as economic, cultural, and social factors on building performance can lead to a better understanding of priorities for green building. This would help sustainability experts to design green buildings assessment tools that not only practice best possible alternatives in a regional scale, but also include all aspects of sustainability that may have been left out before.

CRediT authorship contribution statement

Mehrdad Sadeghi: Writing – original draft, Software, Methodology, Formal analysis, Conceptualization. **Reza Naghedi:** Writing – original draft, Methodology, Conceptualization. **Kourosh Behzadian:** Writing – review & editing, Supervision. **Amiradel Shamshirgaran:** Writing – original draft, Methodology. **Mohammad Reza Tabrizi:** Writing – original draft, Methodology, Data curation, Conceptualization. **Reza Maknoon:** Supervision, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.buildenv.2022.109473.

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