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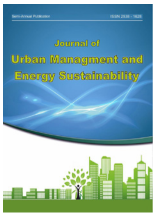

ORIGINAL RESEARCH PAPER

Evaluation and explanation of the design indexes model of zero carbon small-scale buildings with a sustainability approach

Hamid Eskandari

Assistant Professor, Department of Architecture, Faculty of Technical and Engineering, Yasouj University, Yasouj, Iran

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ABSTRACT

Increasing energy efficiency in buildings will significantly impact the reduction of carbon dioxide emissions, environmental damage, and operating costs. Small-scale carbon-neutral building rehabilitation with a sustainability-driven approach demonstrates that tangible, low-carbon retrofits can transform existing built environments while delivering resilient, economical, and environmentally responsible outcomes. In recent years, China has intensified efforts toward small-scale carbon-neutral building rehabilitation within a sustainability-driven framework, advancing practical retrofits, policy support, and innovative financing to decarbonize existing buildings and enhance energy resilience. The research method of this research is analytical and has been conducted in an interpretive and researcher-centered paradigm. The purpose of the research is applied and the structure of the final indexes model is developmental. The method of collecting information is documentary and library, and a questionnaire and interview have been used to conduct the research. First, using the content analysis method and inductive reasoning in developing the initial concepts and reviewing the research background, the initial theoretical framework of the research is refined, and then using the fuzzy Delphi method in the participatory decision-making approach, it is questioned and evaluated in 4 rounds using an elite panel of 19 people in the research field of expertise and finally using the results, the final framework of the indexes is presented. Findings shows, the activity areas and indices indicates that the location and site factors, such as selecting an appropriate building site and paying attention to land characteristics, are fundamental in the development of zero-carbon housing in China and results demonstrate that the integrating these indicators into policy and building codes can institutionalize sustainable practices, ensuring consistency and accountability in zero-carbon housing development.

Running Title: The design indexes model of zero carbon small-scale buildings

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
43	15	03

*Corresponding Author:
Email: *eskandari@yu.ac.ir*
Phone: + 987431005001
ORCID: https://orcid.org/0000-0003-1385-709X

INTRODUCTION

According to the International Energy Agency report, fossil fuel consumption for energy used in buildings is recognized as one of the main sources of carbon dioxide emissions (Bakker, 2016). Increasing energy efficiency in buildings will significantly impact the reduction of carbon dioxide emissions, environmental damage, and operating costs (Bakhshaei and Ramezanian, 2020; Brandon., 2021). By considering various indicators such as using passive systems, utilizing daylight (Cameron and Collins, 2018), improving the building envelope in accordance with the climate (Chen et al, 2021), enhancing the efficiency of electrical lighting systems, and using high-efficiency heating, cooling, and hot water equipment with controlled systems (Dunn, 2019), the carbon emissions from buildings can be reduced.

These indicators can be classified under the domain of "energy efficiency." In low-carbon buildings, the required energy is supplied through the use of renewable energy sources (Feng et al., 2021). Environmentally, for every gigawatt-hour of electricity produced by photovoltaic systems, approximately 1000 tons of carbon dioxide emissions are reduced (Emami, 2023). Given the high importance of energy production in low-carbon buildings, the field of "renewable energy" is defined independently from the field of "energy efficiency." Research indicates that water and energy resources are closely interconnected.

In the process of producing drinking water, energy is consumed and carbon dioxide is emitted during water transport and physical, chemical, and biological treatment (Fischer et al., 2020). By recycling and reusing gray water, monitoring water consumption (Geng et al., 2021), and reducing water demand and consumption in buildings and surroundings (Gholizadeh et al., 2021), "water efficiency" can be increased. The choice of building system type and construction materials throughout the building's life cycle, including raw material extraction, processing, transportation, water and energy consumption during construction, operation, and maintenance, and demolition, directly and indirectly impacts carbon emissions (Gonzalez, 2023). Therefore, recent studies have also addressed the impact of selecting building materials on energy supply and reducing operational costs (He et al., 2021). The selection of the building system and construction method should be aligned with the site and project conditions (Hosseini and Mikhail, 2021). In selecting materials, the entire life cycle of the building should be taken into account (Huang et al., 2022), and climatic and environmental considerations should also be considered (IEA, 2020). Furthermore, the reuse of materials, the use of recycled materials, and materials that are more easily recyclable can reduce carbon emissions in buildings (Ismaeil et al., 2023; Kazemi and Taheri, 2023). The impacts of material recycling on reducing greenhouse gases and creating economic benefits in construction projects have also been highlighted in recent studies (Klein, 2014).

These indicators can be classified under the domain of "materials and construction methods." The architecture of the building and the architect's decisions determine the quality of the building and have a significant impact on energy efficiency and the level of carbon emissions from the building (Lehmann, 2013). Reducing energy consumption by lowering energy demand should be considered from the design stage by using climatic design (Li, 2020). Rethinking the foundation of the building (Li et al., 2020), the form, shape, and infrastructure of the building, as well as modular design (Lichtenstein, 2020), can significantly contribute to achieving low-carbon buildings.

it seems that zero carbon homes will become an integral part of urban and residential planning in the coming years. Public awareness, supportive policies and cross-sectoral cooperation will help to achieve these goals, and it will be possible for future homes to be built in a sustainable and low-carbon way despite the scarcity of resources. These concepts are also seen in new designs in China. (MCManus, 2021). (Fig. 1)

In this regard, a study has shown that redesigning interior spaces according to user needs can significantly increase energy efficiency (Nourian et al., 2021). These indicators can be classified under the domain of "building architecture." Improving the quality of the indoor environment and creating comfort for users, along with maintaining health and enhancing productivity and well-being, also leads to a reduction in carbon emissions (Nykvist and Nilsson, 2015). Indicators such as providing thermal comfort and lighting (Pearson, 2009) and monitoring and controlling indoor air quality (Rattenbury, 2008) can be classified under the domain of "indoor environmental quality." In the design of low-carbon buildings, the importance of appropriate building placement in the city and access to high-utility uses and public transport has been emphasized. Emissions from transportation can increase operational emissions by up to 140% (Sadeghi et al., 2020). Additionally, considering user behavior patterns and their impact on the design of public spaces can help reduce emissions (Rice, 2016).

Landscaping on-site, taking into account climatic considerations and site characteristics, can also be effective in reducing consumption and carbon emissions (Sadeghi et al., 2022) In recent decades, extensive research has been conducted on zero carbon housing in China.(Li et al., 2020) focused on the impact of sustainable design on carbon emission reduction, demonstrating that the use of green materials can significantly reduce environmental impacts.(Wang et al. ,2021) also examined strategies for optimizing energy consumption in new buildings, emphasizing that the use of renewable technologies will assist in achieving zero carbon goals. (Zhang et al.,2022) centered their research on the environmental and economic impacts of zero carbon systems on local communities, showing that these buildings can improve the quality of life for residents. (Chen et al.,2023) conducted a study evaluating the energy efficiency of zero carbon buildings in various regions of China and provided suggestions for optimizing designs and material selections. (Liu et al.,2024) analyzed the trends and challenges surrounding the creation of zero carbon housing and stressed the need for effective policies and the transfer of new technologies to the market. (Xu et al.,2022) investigated the impact of climate change on zero carbon building design with a focus on environmental sustainability, pointing out that these changes affect how buildings are designed and constructed. (Sun et al.,2023), through research on the use of solar energy in residential buildings, concluded that energy consumption can be significantly reduced. (Gao et al.,2021) conducted a study on the role of artificial intelligence in optimizing building energy use, examining its positive effects on the design and management of sustainable buildings. (Additionally, Huang et al.,2024) emphasized the use of recycled materials in construction and showed that this approach can help reduce carbon emissions.(Zheng et al.,2022) explored nature-based design strategies for zero carbon buildings and analyzed their positive effects on resident health. (Tian et al.,2023) addressed the financial and economic challenges of creating zero carbon housing, demonstrating that the need for high initial investments is one of the main barriers to these projects. (Peng et al.,2021) examined the influence of culture and social behaviors on the acceptance of zero carbon housing, emphasizing the necessity for cultural advancements to enhance resident awareness. Finally, (Shi et al.,2023) investigated the relationship between resident experiences and the design of sustainable buildings, showing that positive resident experiences can lead to wider acceptance of such buildings. These studies indicate significant progress in China's efforts to achieve zero carbon objectives in the housing sector. Based on the reviews conducted in previous chapters and this chapter regarding the background of zero carbon building studies in housing and its industrialization, a framework of general factors can be achieved. The literature review indicates that the factors influencing carbon emission reduction in buildings can be classified into seven areas: "location and site," "building architecture," "materials and construction methods," "energy efficiency," "water efficiency," "indoor environmental quality," and "renewable energy." In the next step, the UK Carbon Neutral Building Framework (Taleghani et al., 2020), the Canadian Zero Carbon Building Design Standard (Smith, 2015), Zero Carbon LEED 3 (Sundstrom, 2020), Zero Carbon EDGE 4 (Thompson, 2016), and the New Low-Carbon Residential Building Design Framework in Australia (Wang and Zhang, 2022) were reviewed. The emphasized areas in these frameworks and standards are included in Table 1. The present study uses the Delphi method as a research tool to evaluate the factors impacting the design of low-carbon buildings in China. The Delphi method was specifically chosen for its multi-faceted and participatory approach, which involves engaging with key stakeholders and decision-makers in the field of sustainable building design (Wang et al., 2020; Williamson, 2020).

(a) (b)

Figure 1: (a) Example of a general low carbon community in the Shanghai area; (b) The overall structure of the distributed solar power generated system applied in the community. (Zhou et al., 2022)

Methodology

The research method of this research is analytical and has been conducted in an interpretive and researcher-centered paradigm. The purpose of the research is applied and the structure of the final indexes model is developmental. The method of collecting information is documentary and library, and a questionnaire and interview have been used to conduct the research. First, using the content analysis method and inductive reasoning in developing the initial concepts and reviewing the research background, the initial theoretical framework of the research is refined, and then using the fuzzy Delphi method in the participatory decision-making approach, it is questioned and evaluated in 4 rounds using an elite panel of 19 people in the research field of expertise and finally using the results, the final framework of the indexes is presented.

Description of the Delphi method

The Delphi method is known as a qualitative research method for solving complex problems and reaching consensus in various fields, including sustainable development and policy making.

This method has been well implemented especially in the review and evaluation of indicators in research related to sustainable and low-carbon buildings in other countries and has obtained acceptable results. The fuzzy Delphi method is a research technique that aids in analyzing and gathering expert opinions across various fields. This method is particularly useful for examining complex and multifaceted issues. In the context of zero carbon buildings, the fuzzy Delphi method can help identify and prioritize the factors that impact the design and construction of these types of buildings. As defined, this method involves multiple rounds of questionnaires where expert opinions are collected and analyzed (Zare & Gholizadeh, 2021). Utilizing the fuzzy Delphi method allows researchers to achieve a consensus on the importance and necessity of specific indicators while evaluating diverse opinions. This method accounts for the uncertainties stemming from varied perspectives by employing fuzzy techniques, thus facilitating decision-making under conditions of ambiguity (Zhang & Zhou, 2022). This unique characteristic makes the fuzzy Delphi method a suitable tool for exploring issues such as the design of zero carbon buildings, which require input from various stakeholders and specialists. Research focusing on identifying selected indicators affecting zero carbon buildings can achieve a more precise understanding through the application of the fuzzy Delphi method. These indicators may encompass various aspects of design, construction materials, and renewable energy technologies (Zhou et al., 2022). For instance, studies that investigate challenges in zero carbon construction reveal that expert opinions can significantly influence the development of new and effective solutions. Given that zero carbon buildings require advanced and efficient designs, the use of the fuzzy Delphi method can facilitate a more in-depth analysis of user needs and the exploration of optimal solutions.

In this regard, feedback from experts in areas such as energy, environment, and health and well-being can be invaluable. This approach enables researchers to gather diverse viewpoints and reach comprehensive conclusions. Ultimately, the fuzzy Delphi method serves as an effective tool for identifying and prioritizing the indicators that influence zero carbon buildings. This method allows researchers to thoroughly consider the insights and experiences of experts and contribute to the development of strategies aimed at achieving zero carbon objectives.

Steps to implement the Delphi method

The Delphi method involves a series of questionnaires or stages that are carried out sequentially with controlled feedback. These stages generally include five steps. In each stage of the research, the Delphi panel members, consisting of experts in the field of low-carbon building design, respond to questions. One notable feature of this method is the anonymity of the panel members, which allows them to express their opinions freely without being influenced by friendly or competitive judgments.

In practice, Delphi panel members participate more than once in answering questions. This repetition provides them with an opportunity to reconsider their decisions by reviewing feedback from other experts on each indicator. The exchange of data between panel members is controlled by the researcher. The researcher collects individuals' responses and, after evaluating them, passes the results on to the next round. This process prevents personal discussions among individuals and thus helps facilitate and streamline the work and research process.

Determining the expert group (Delphi panel)

The Delphi method is used to gather the opinions and experiences of experts on the research subject, and these individuals are known as the Delphi panel (Linstone and Turoff, 1975a). The selection of the type of expertise and the number of panel members is very important (Zhao, 2019), which is why there are guidelines for determining the number and composition of panel members. According to Witkin's recommendations, the number of specialists in the Delphi panel should be less than 50. ensuring that the panel is large enough to cover diverse opinions while still being small enough to easily reach a consensus among members. In contrast, Clayton suggests that the number of people in the panel should be between 15 and 30. Some researchers believe that the exact number of panel members should not be emphasized; instead, attention should be paid to their relevant capabilities and knowledge in the study area (Zhou et al., 2021). Based on Witkin's recommendations and a review of similar research, a panel of 30 experts was chosen for the first phase of this study. Given the nature of the research topic, the necessary characteristics for participants in the Delphi panel were specified. In this study, all panel members have studied in one of the fields related to buildings and are familiar with sustainability issues. The panel consists of three groups: "policymakers and decision-makers," "researchers," and "practitioners in the construction industry," with ten members invited from each group. These panel members have a comprehensive mastery of the subject based on their work and experience. The profiles of these individuals are presented in Table (1). The experts from the "policymakers and decision-makers" group in the Delphi panel influence high-level decision-making and collaborate with the government.

According to the snowball technique, these professionals can provide feedback based on their experiences in decision-making, policymaking, and developing regulations and standards, guiding the construction industry toward the development of low-carbon buildings as political changes arise. The presence of "researchers" in the Delphi panel is of particular importance in this study, as they have different perspectives and insights compared to policymakers. Given their research backgrounds, these individuals can propose new ideas and solutions based on innovative methods and technologies in developed countries. Practitioners in the construction industry, in their empirical capacity as designers, consultants, and contractors, can also provide their feedback. These individuals have sufficient experience in construction and are familiar with the laws, regulations, challenges, and barriers in the construction industry in the country. Their experience predominantly focuses on sustainable and low-energy constructions, and they also have adequate knowledge of conventional construction materials and methods.

Tabel 1: Delphi panel

Area of activity	Department/Unit	Number	Description
policy makers and decision makers	Ministry of Ecology and Environment	5	These people are familiar with the concept of zero carbon building and are graduates of architecture, civil engineering and urban planning who are working in related units.
	National Housing Administration		
	Ministry of Housing and Urban-Rural Development		
Researchers	Peking University	10	These people have a doctorate degree and have researched in the field of zero carbon buildings, energy and housing industrialization
	Tsinghua University		
Activists in the field of construction	Private companies (Hiron Architecture, China Energy Consulting)	4	These people have practical activities with an educational background related to the subject of residential buildings and the subject of energy

Implementation of the Delphi method

TheAfter identifying the areas and indicators that affect the design of low-carbon buildings, the Delphi process for evaluating these indicators began. The Delphi process includes several fundamental stages and each of the stages will be described. In the first step of the research, indicators and areas affecting low-carbon buildings were identified through a literature review, followed by the initial classification of these indicators. After this stage, the first round questionnaire was prepared. To ensure the validity of the questionnaire, copies were delivered in person to six individuals (two policymakers, two researchers, and two practitioners from the construction industry) before final distribution. In this meeting, discussions and exchanges of views regarding the indicators mentioned in the questionnaire took place. After analyzing the first round questions, the second round questionnaire was prepared and sent to those individuals. The results confirmed the validity of the questionnaire. For assessing the reliability of the questionnaire, Cronbach's alpha coefficient was used, with a value of 0.982 indicating high reliability.

In the second step, based on the characteristics mentioned in the previous section, the Delphi panel members were identified, and they were invited to participate. In the first meeting, they were given the necessary explanations regarding their responsibilities to respond to the questionnaires in several stages and to continue their collaboration until the end of the process. They were also assured that their responses would remain confidential throughout all stages. In the third step, the first round questionnaire was distributed among 30 panel members, and all individuals responded to the questionnaire. The panel members evaluated the indicators derived from the literature review based on their importance in the design of low-carbon buildings in Iran using a Likert scale (from 1 to 5, including very low importance, low, medium, high, and very high). To facilitate brainstorming, the questionnaire included the option for panel members to add their suggested indicators based on their professional backgrounds. Additionally, panel members could propose that some indicators be combined and presented as a single overall indicator. After collecting and analyzing the responses with SPSS software, statistical indicators such as mean, standard deviation, and interquartile range were extracted for each indicator. In the fourth step, the second round questionnaire was prepared based on the feedback received from the first round questionnaire. The aim of this questionnaire was to reassess the indicators that achieved consensus as well as to reach consensus on indicators that did not, and to evaluate the indicators raised by the panel members in the first round questionnaire. This questionnaire was similar to the first round, with the difference that the mean responses were listed for each indicator. Experts could evaluate the importance of each indicator and revise their responses based on the opinions of other experts.

Consensus Evaluation

It is an important step of the Delphi method. Consensus means the agreement of opinion among experts on a specific topic, and its achievement is measured using data dispersion measurement methods.

Interquartile range

Interquartile Range (IQR) is one of the most commonly used methods for measuring data dispersion in assessing the level of consensus in the Delphi method. The interquartile range indicates the distance between the third quartile (Q3) and the first quartile (Q1) and is calculated using the following formula: $IQR = Q3 - Q1$ (Relation 1)

The acceptable range in the interquartile range depends on the spectrum of responses from the Delphi panel (Linstone and Turoff, 1975b). In this research, experts evaluate each indicator based on a 7-point Likert scale (Shields et al., 1987) from 1 to 5 according to its importance:

- 1: Very low importance
- 2: Low importance
- 3: Medium importance
- 4: High importance
- 5: Very high importance

Consensus Criterion

In studies where responses are provided on a five-point Likert scale, an interquartile range of $IQR \leq 1$ indicates the establishment of consensus.

Standard Deviation

To determine the level of consensus and demonstrate data dispersion relative to the mean for each indicator, the standard deviation (SD) is

also calculated. The standard deviation is the square root of the average squared distance of values from the mean and is calculated using the following formula:

$$SD = \sqrt{(\sum(Xi - \bar{X})^2 / n)} \quad \textbf{(Relation 2)}$$

Where in this relation:

- SD: Standard Deviation
- Xi: Value of data point i
- $\bar{X}$: Mean of the data
- n: Number of data points

These two tools (interquartile range and standard deviation) help researchers easily assess the level of consensus among respondents and obtain a more precise analysis of the data.

$$SD(x) = \sqrt{(\sum(Xi - \bar{X})^2 / (n - 1))} \quad \textbf{(Relation 2)}$$

In this research, two indicators of standard deviation and interquartile range were used to evaluate the consensus of Delphi panel members. This approach helped us to determine which indicators were agreed upon by the Delphi panel members in achieving low-carbon buildings and which should be removed from the list of indicators.

Consensus evaluation results

According to the results presented in Table 3:

- The standard deviation of the indicators ranged from 0.428 to 0.922.
- The interquartile range (IQR) for all indicators was one or less than one.

These results indicate the establishment of consensus among the experts, as the low standard deviation and interquartile range of less than one suggest a high agreement among panel members regarding the importance of the indicators under review.

Importance Assessment of indexes

In this research, the mean was calculated to measure the importance of each indicator. The weighted average of each indicator is also reported in the findings section. This criterion was used as a key tool for understanding the relative value of each indicator in the design of low-carbon buildings. This approach allows us not only to assess consensus among panel members but also to aid in the evaluation and prioritization of key indicators, leading to more informed and efficient decision-making in this area.

Based on the consensus among the Delphi panel, the indicators for low-carbon building design in Iran were classified into seven areas and 94 indicators as shown in Figure 2, which include: location and site, building architecture, materials and construction methods, energy efficiency, water efficiency, indoor environmental quality, and renewable energy. It is worth mentioning that the priority of the indicators is not considered in this figure. Additionally, the importance of each indicator for achieving low-carbon buildings in Iran was assessed, and the results are presented in this section.

Tabel 2

Area of activity	Indexes ads.	Index	Interquartile range	Standard deviation	Consensus evaluation
Location and Site	4	Choosing a building site	1	0/802	
		Pay attention to the characteristics of the land	1	0/669	
		Landscaping on site	0	0/583	
		Reducing the heat island effect	0	0/539	
Architecture Building	9	Climate design	0	0/428	
		Preference for using existing buildings on site	1	0/618	
		Rethinking the form, shape of the building and the height of the floors	1	0/548	
		Rethinking the physical plan and area of spaces and building infrastructure	1	0/618	
		Rethinking the area and placement of transparent and translucent surfaces	1	0/705	
		Space layout and zoning	1	0/548	
		Modular design	1	0/618	
		Flexibility of spaces	1	0/686	
		Design for dismantling	1	0/725	
Materials and methods of construction	11	Selection of materials based on climatic and environmental considerations	1	0/575	
		Use of recycled materials and building materials and systems that are more recyclable and reuse of materials and components	1	0/575	
		Using materials appropriate to the lifespan of the building	1	0/698	
		Use of certified materials	1	0/698	
		Correct design of connection details	1	0/575	
		Waste management in demolition and construction	1	0/676	
		Optimal design of structures and structural elements and optimal use of materials	1	0/840	
		Prefabricated	1	0/575	
		Building Information Modeling	1	0/705	
		Choosing a building system in accordance with the location and project conditions	1	0/647	
		Using machinery with appropriate capacity on site	1	0/784	

Energy Efficiency	10	Utilizing passive systems	1	0/511	
		Upgrading the building's exterior shell to suit the climate	1	0/461	
		Taking advantage of daylight	1	0/502	
		Increasing the efficiency of the electric lighting system	1	0/594	
		Use of high-efficiency heating, cooling, and hot water equipment	1	0/511	
		Equipment control	1	0/511	
		Measuring and monitoring energy consumption in buildings and energy management	0	0/539	
		Type of fuel used	1	0/594	
		Reducing energy needs and consumption by using storage technologies	1	0/594	
		Performing building energy modeling	1	0/514	
		Reducing water needs and consumption in buildings and grounds	1	0/705	
Water efficiency	5	Monitoring and supervising water consumption in the building and grounds	1	0/826	
		Recycling and reuse of grey water	1	0/767	
		Using organic methods of water collection and purification	1	0/922	
		Optimal irrigation of green spaces and planting native plants	1	0/895	
Indoor environmental quality	4	Providing comfortable lighting conditions	1	0/786	
		Providing thermal comfort conditions	1	0/767	
		Measuring and controlling proper indoor air quality	0	0/725	
		Control by building energy management systems	1	0/786	
Renewable energy	2	Generating electricity using renewable resources	1	0/618	
		Solar water heater	1	0/511	

Based on the consensus among the Delphi panel, the indicators for low-carbon building design in Iran were classified into seven areas and 94 indicators as shown in Figure 2, which include: location and site, building architecture, materials and construction methods, energy efficiency, water efficiency, indoor environmental quality, and renewable energy. It is worth mentioning that the priority of the indicators is not considered in this figure. Additionally, the importance of each indicator for achieving low-carbon buildings in Iran was assessed, and the results are presented in this section.

DISCUSSION AND FINDINGS

According to the consensus among the Delphi panel, the indicators for low-carbon building design in Iran were classified into seven areas and 94 indicators, which include: location and site, building architecture, materials and construction methods, energy efficiency, water efficiency, indoor environmental quality, and renewable energy. It should be noted that the priority of the indicators is not considered in this framework. Additionally, the importance of each indicator for achieving low-carbon buildings in Iran was assessed, and the results are presented in this section. (Fig. 2-8)

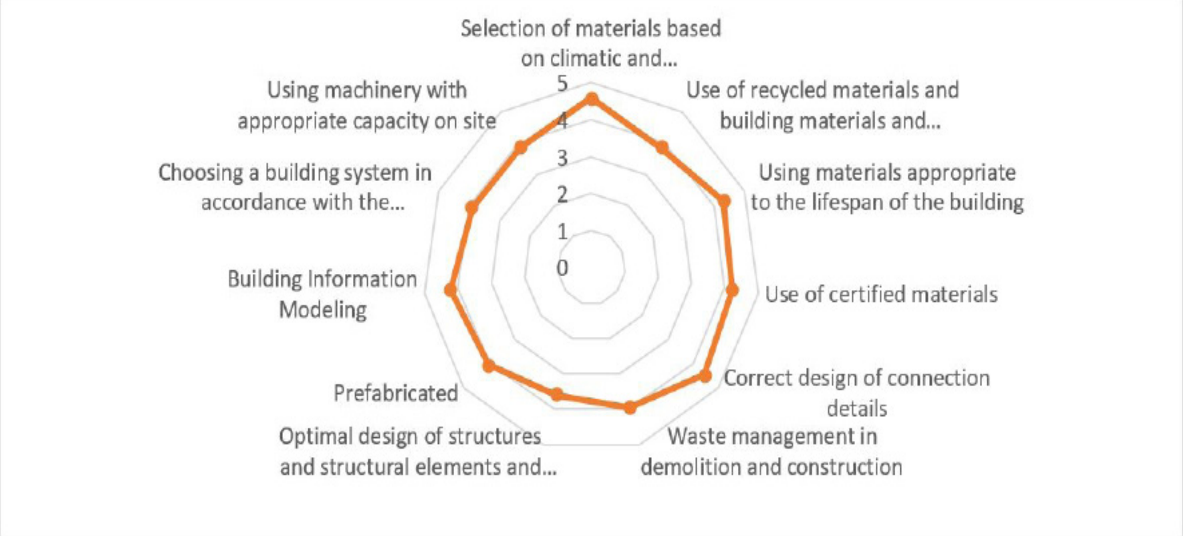
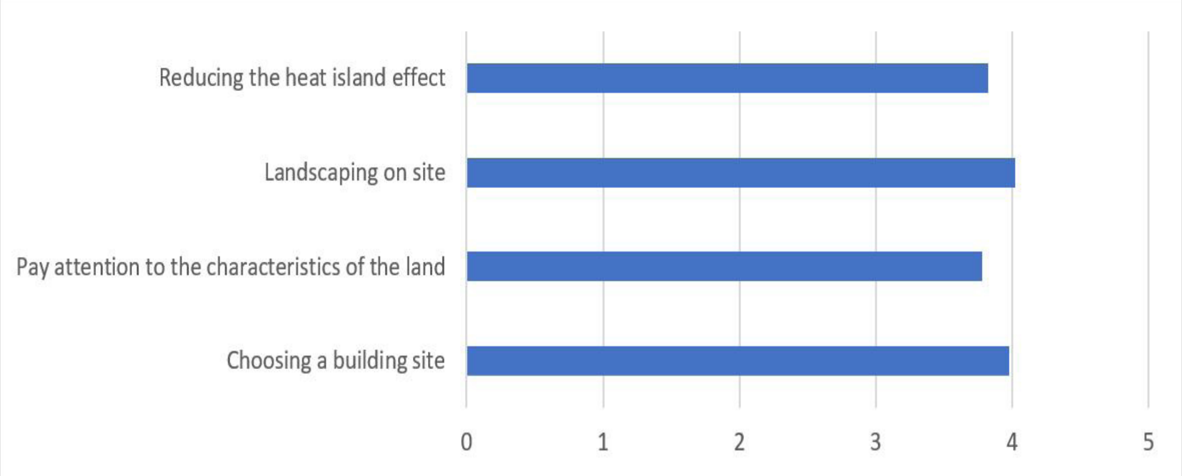


Figure. 2: Average weight of materials and construction method indicators according to the importance of the indicator in low-carbon building design in Iran according to the industrialization approach in residential buildings in China



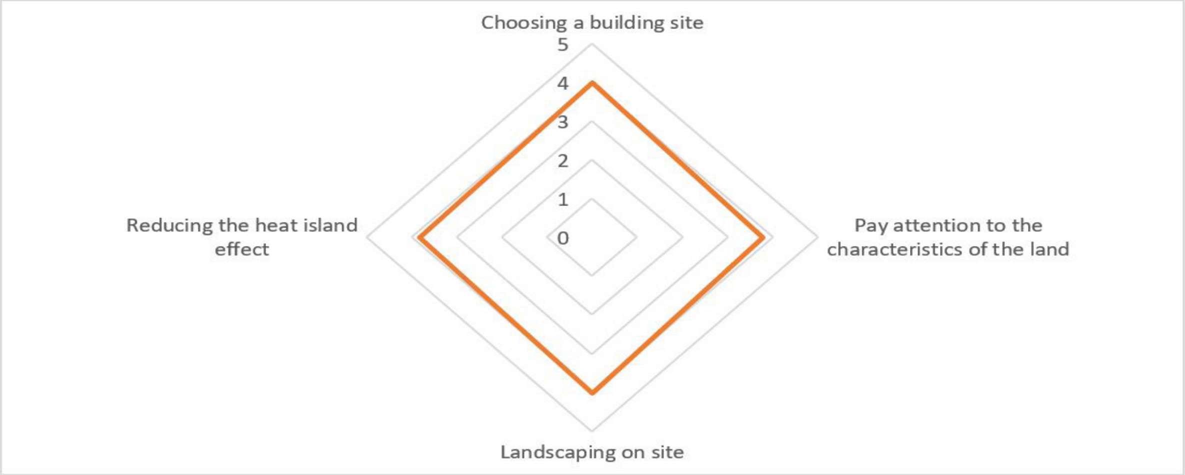


Figure 3: Average weight of location and site indicators according to the importance of the indicator in low-carbon building design in China

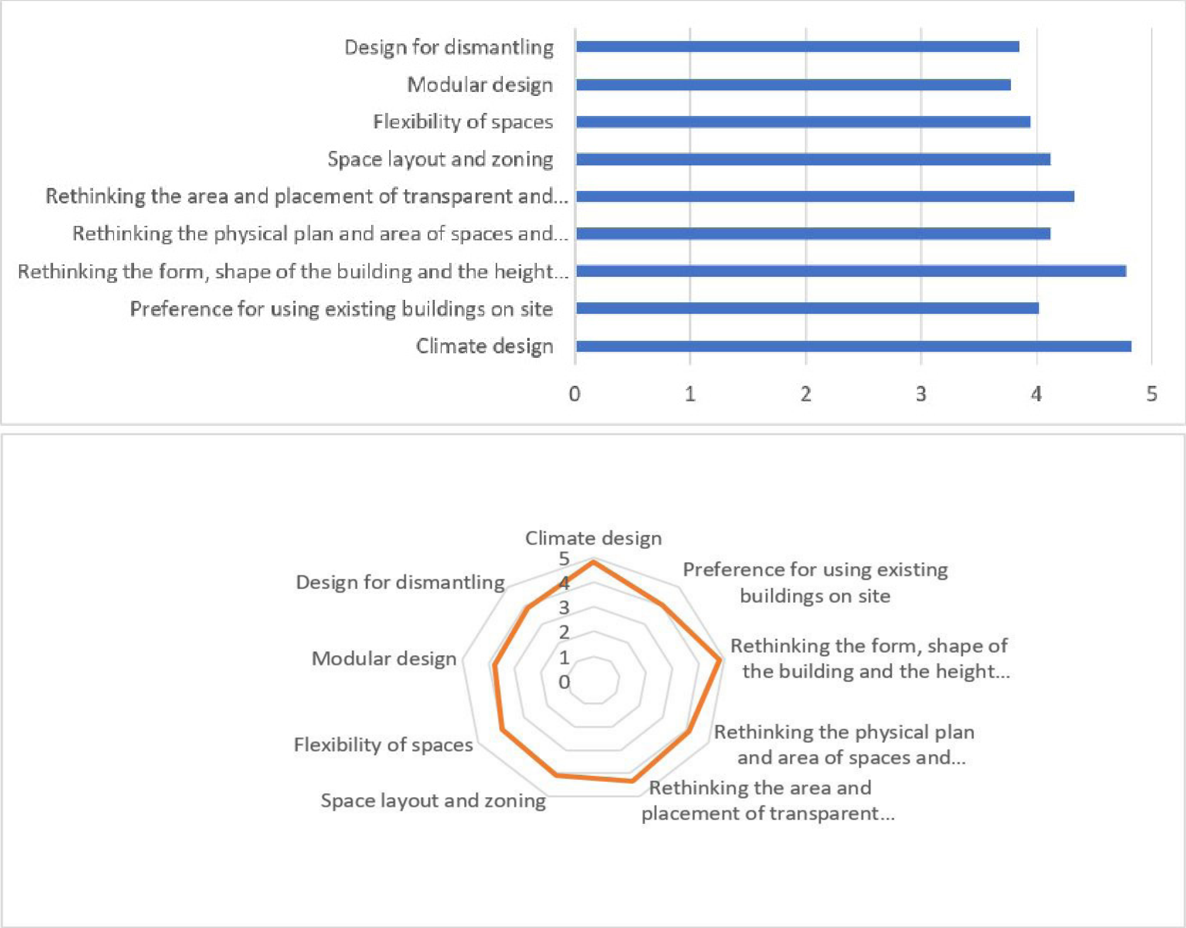


Figure 4: Average weight of building architecture indicators according to the importance of the indicator in low-carbon building design in China

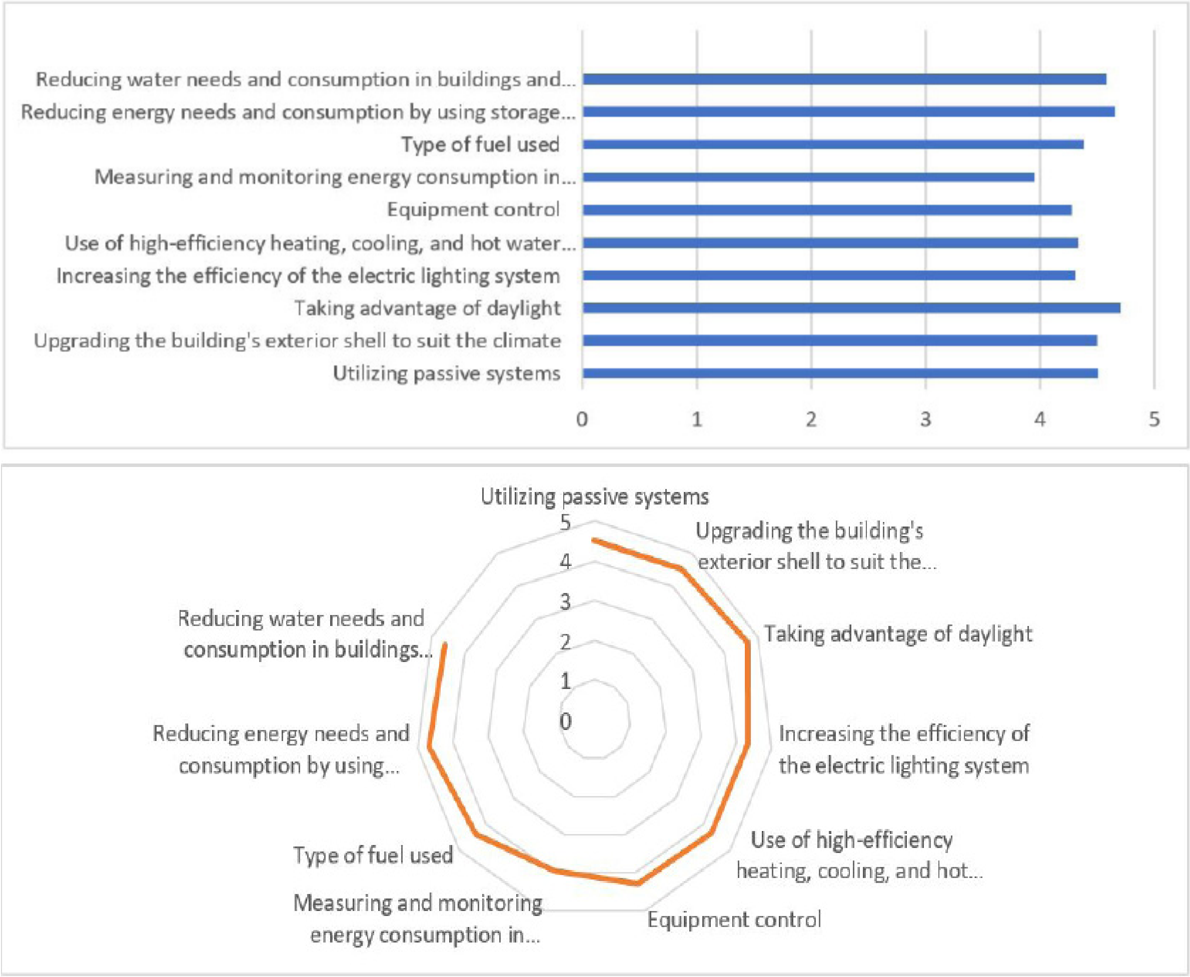
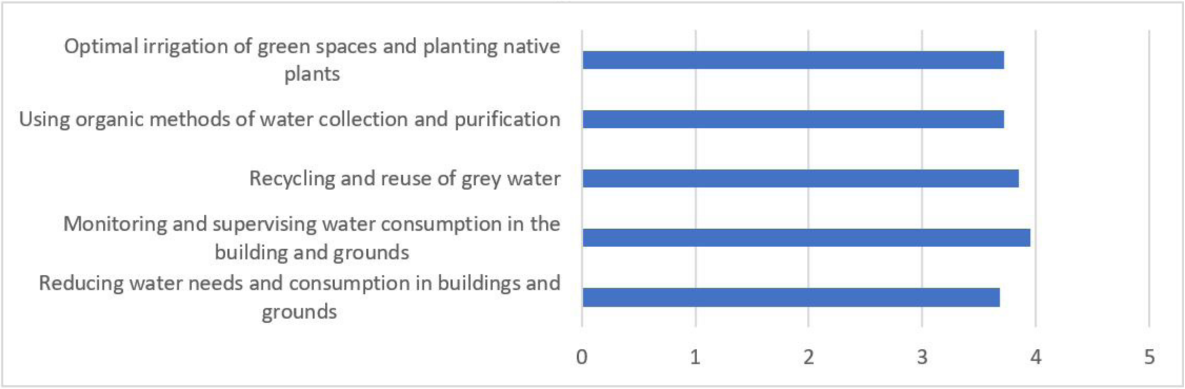


Figure 5: Average weight of Energy efficiency indicators according to the importance of the indicator in low-carbon building design in China



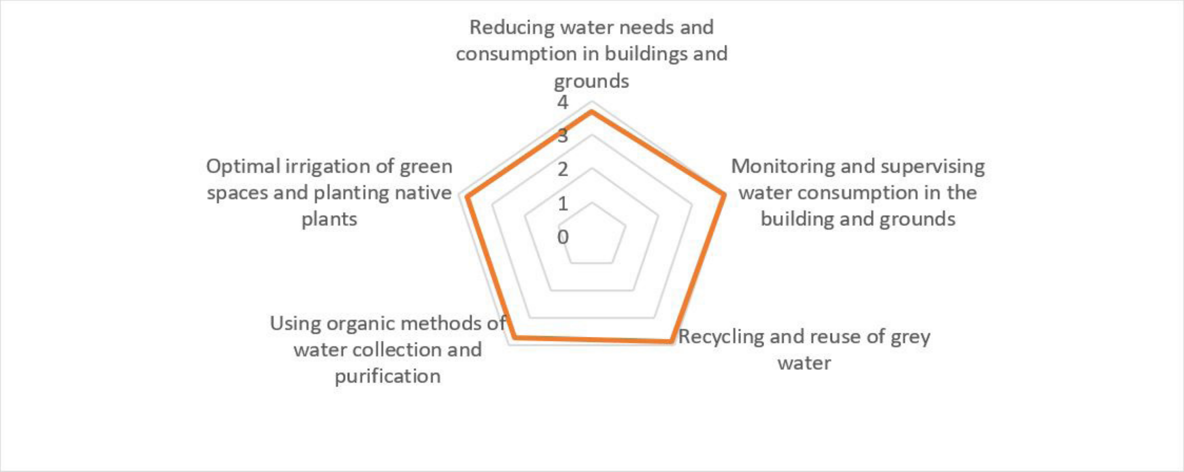
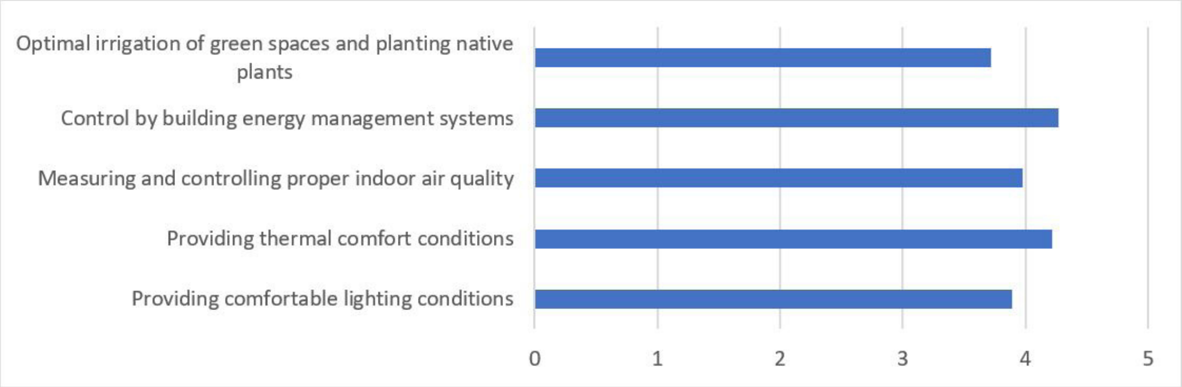


Figure 6: Average weight of Water efficiency indicators according to the importance of the indicator in low-carbon building design in China



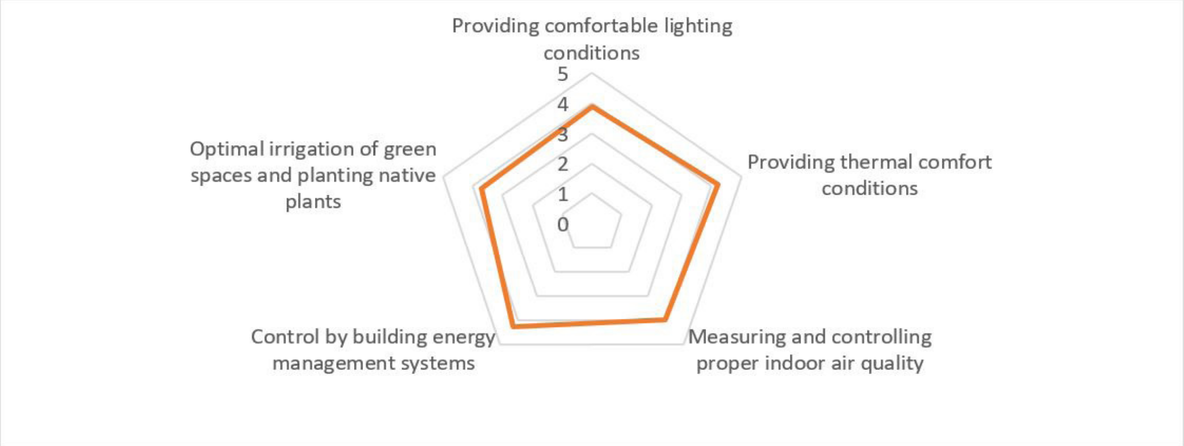


Figure 7: Average weight of Indoor environmental quality indicators according to the importance of the indicator in low-carbon building design in China

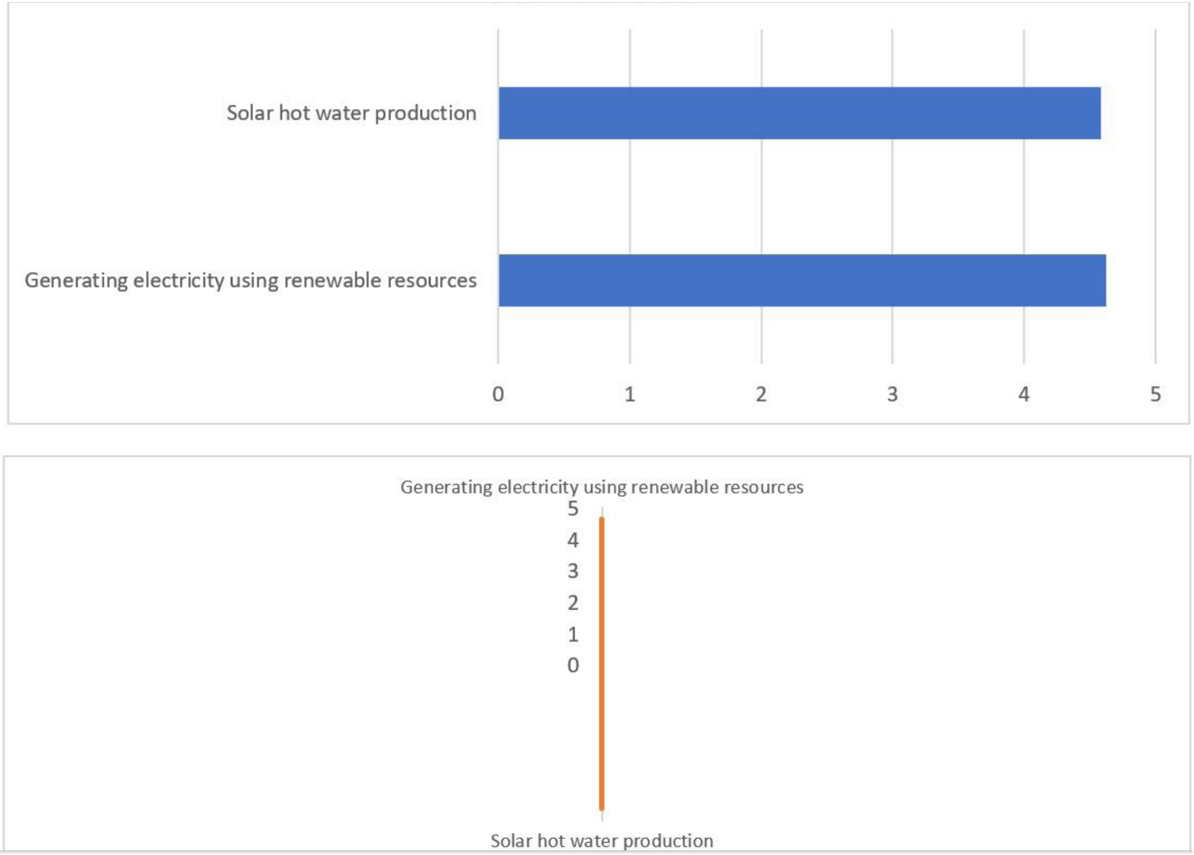


Figure 8: Average weight of Indoor environmental quality indicators according to the importance of the indicator in low-carbon building design in China

DISCUSSION AND FINDINGS

RESULT AND CONCLUSION

The analysis of the activity areas and indices indicates that the location and site factors, such as selecting an appropriate building site and paying attention to land characteristics, are fundamental in the development of zero-carbon housing in China. These factors have high importance and consistent evaluation scores, emphasizing the necessity of careful site selection to optimize environmental benefits. Architectural considerations, including climate-adaptive design, rethinking building forms, spatial layout, and forming flexible structures, demonstrate a significant impact on reducing energy consumption and adapting buildings to local conditions. The high consensus on these indicators reveals their central role in achieving sustainable and low-carbon housing. Material selection, especially based on climatic considerations, recyclability, lifespan, and the use of certified materials, underscores a shared commitment to environmentally friendly construction practices. The application of advanced construction technologies, such as Building Information Modeling and prefabrication, also plays a vital role in enhancing efficiency, minimizing waste, and ensuring precise implementation in sustainable housing projects. Energy efficiency measures, including passive heating and cooling systems, daylight utilization, and high-efficiency equipment, are prioritized to reduce energy use, supported by their high evaluation scores. Water efficiency indicators, such as reducing water needs, greywater recycling, and organic water collection methods, are critically important in conserving this vital resource, with high consensus scores highlighting their relevance. Indoor environmental quality, especially providing comfortable lighting and thermal conditions, along with indoor air quality control, directly affects user well-being and are deemed essential components in ecological housing. Renewable energy sources, notably solar-based systems like solar water heaters and electricity generation, are recognized for their contribution to lowering carbon footprints and are therefore given considerable emphasis. The overall evaluation suggests that integrating these diverse indicators into a comprehensive framework is imperative. Prioritizing climate-responsive and resource-efficient design, adopting innovative construction materials and technologies, and implementing renewable energy solutions collectively foster the development of truly sustainable, zero-carbon housing. The high agreement levels across various indicators reflect a shared understanding and strategic consensus crucial for advancing environmentally responsible residential architecture in both Iran and China. Ultimately, these insights can guide policymakers, architects, and developers in designing and implementing more effective and sustainable zero-carbon housing models tailored to local contexts while adhering to global sustainability standards.

Furthermore, the evaluation underscores the importance of integrating passive and active energy systems to maximize energy savings and minimize reliance on non-renewable sources. The emphasis on upgrading building envelopes to suit local climate conditions reflects a strategic approach to energy conservation, illustrating a strong consensus among experts. The role of advanced water management techniques, including optimal irrigation and native plant use, supports sustainable landscaping that reduces water consumption and ecological impact. Indoor environmental quality indicators, such as thermal comfort and controlled indoor air quality, not only enhance occupant well-being but also contribute to the overall sustainability performance of the housing. The deployment of renewable energy technologies, especially solar-based solutions, is seen as critical in reducing the carbon footprint and promoting energy independence for residential buildings. The high evaluation scores for these indicators demonstrate their vital importance and feasibility within the context of the two countries' development frameworks. The use of environmentally responsible materials and construction methods aligns closely with global sustainability trends, emphasizing recyclability, lifespan, and minimal environmental impact. Technology integration, especially through BIM and prefabrication, offers mechanisms for accurate planning, resource optimization, and reducing construction waste—key factors that influence project success and sustainability outcomes. The overall consensus results reveal that a holistic approach combining site selection, innovative architecture, advanced materials, and renewable energy sources is essential to achieve true zero-carbon housing. Such an approach not only addresses climate and resource challenges but also offers scalable solutions adaptable to different regional contexts in Iran and China. The findings suggest that policymakers and stakeholders should prioritize these high-impact indicators during planning and implementation phases, ensuring coherence between technical design and sustainability goals. Moreover, continuous monitoring and adaptive management practices, supported by energy and water performance tracking, are fundamental to maintaining and improving the efficiency of zero-carbon housing over its lifecycle. This comprehensive evaluation provides a valuable roadmap for future development, encouraging the adoption of integrated strategies that balance ecological, economic, and social dimensions. Ultimately, fostering collaboration among architects, engineers, policymakers, and local communities is key to translating these indicators into tangible, sustainable residential solutions. The shared insights and high levels of agreement highlight that both Iran and China are on a converging path toward sustainable housing, emphasizing innovation, environmental responsibility, and occupant health as core principles. These shared goals emphasize the importance of tailored, context-specific strategies that leverage local resources, technology, and expertise to build resilient, low-carbon communities for future generations. In addition, the comprehensive evaluation underscores that education and awareness about sustainable building practices are crucial for successful implementation of zero-carbon housing. Promoting knowledge-sharing and capacity-building initiatives among designers, builders, and residents can accelerate the adoption of green standards and innovative solutions. Furthermore, policy frameworks that incentivize the use of renewable energy systems, sustainable materials, and energy-efficient technologies are vital to overcoming financial barriers and encouraging wider adoption. The evaluation also highlights the need for robust monitoring systems that track performance indicators such as energy consumption, water usage, and indoor environmental quality. These systems can facilitate data-driven decision-making and continuous improvement efforts, ensuring the long-term sustainability of housing projects. Cross-national collaboration between Iran and China in research, technology exchange, and policy development could foster shared advancements in zero-carbon building practices, leveraging their respective strengths and experiences. Such partnerships can also facilitate the adaptation of successful strategies to local socio-economic contexts, enhancing overall effectiveness. The high agreement on the importance of integrating renewable energy, water conservation, advanced materials, and passive design strategies indicates a shared recognition of the multipronged approach necessary to address climate and resource challenges comprehensively. This holistic perspective is essential for developing resilient, adaptive, and scalable solutions that can be applied across different regional environments within both countries. The significance of stakeholder engagement is also evident; involving local communities in the design process ensures that solutions meet users' needs while fostering acceptance and long-term sustainability. Additionally, integrating these indicators into policy and building codes can institutionalize sustainable practices, ensuring consistency and accountability in zero-carbon housing development. The study's findings advocate for a multidisciplinary approach that aligns architecture, engineering, environmental sciences, and social sciences to develop innovative, sustainable residential models. As urbanization accelerates, the importance of such comprehensive strategies becomes even more critical to prevent further environmental degradation and to promote healthier living environments. The convergence of expert opinions, reflected in the high consensus scores across multiple indicators, reveals a collective willingness to pursue ambitious sustainability targets, paving the way for transformative change in the housing sector of both Iran and China. Emphasizing local adaptation, technological innovation, and policy integration, these findings provide a clear roadmap for future initiatives aiming to achieve zero-carbon residential buildings at scale. Moving forward, widespread implementation of these high-impact indicators can significantly contribute to reducing overall carbon emissions, conserving natural resources, and improving the quality of life for residents. The synthesis of expert consensus, technical feasibility, and environmental necessity underscores the critical importance of coordinated efforts among all stakeholders to realize the vision of truly sustainable, zero-carbon housing in diverse regional contexts.

Practical and policy suggestions for developing zero-carbon housing

In order to develop zero-carbon buildings, the following suggestions are made:

•Development and implementation of national and international standards: It is necessary for the national standards of both countries to be updated and in line with international standards.

•Creation of financial and incentive systems for investment in green buildings: granting tax exemptions, low-interest loans, and joint investments.

•Development of domestic technologies and localization of foreign technologies: holding training courses, supporting research and development, and transferring world-class technologies to domestic communities.

•Public education and culture: holding information campaigns, raising awareness about the benefits of low-carbon buildings, and encouraging residents and construction activists to accept this concept.

•Establishment of international cooperation and exchange of experiences: taking advantage of the successful experiences of other countries, and participating in global projects.

Although the opportunities for developing low-carbon buildings in both countries are significant, challenges such as limited financial resources, unsustainable technologies, lack of comprehensive policies, and cultural resistance exist. However, the high potential for investment in technology, abundant natural resources, and the global desire for sustainable development provide great opportunities to overcome these obstacles. Developing indigenous technologies, utilizing a skilled workforce, and creating a competitive market are key strategies in overcoming these challenges. Technological advances, supportive policies, and changing societal attitudes will play an important role in the development of low-carbon buildings in the future. In Iran, there is a need to take macro-policies of green development seriously and align public and private investments. In China, continuing technological development and market development can make the country one of the main paths in the global arena. In both countries, international cooperation, scientific research, and continuous education will pave the way to achieving zero-carbon buildings. As a result, it can be said that the development of zero-carbon buildings requires a comprehensive, multifaceted approach and international cooperation. This area has great potential to reduce the negative impacts of construction industry activities on the environment and plays an important role in achieving the Sustainable Development Goals. Despite the existing challenges, global and regional opportunities and potentials make this path smoother. Both countries, Iran and China, must put smart policies, new technologies, and effective culture building on their agendas so that they can achieve global standards in the field of green and low-carbon buildings in the near future. These efforts will not only help the environment, but also improve the quality of life, economy, and society, and will put Iran and China on the path of sustainable, green, and resilient development.

Nanomaterials are widely used in low-carbon construction, especially in improving strength, weight reduction, and increasing resistance to biological agents. Nanotechnology can be exploited in strengthening building materials, insulation, and self-cleaning systems to increase the overall efficiency of the building. The use of digital construction technologies, especially in the form of building information modeling (BIM), enables the design and management of construction projects with high accuracy and efficiency. This technology enables the reduction of waste and construction errors, optimal management of resources, and facilitation of construction processes. Prefabricated construction technology plays an important role, especially in fast construction, cost reduction, and improvement of the final quality of the building. With prefabricated processing and formwork, quality levels can be standardized and operating costs can be reduced. Smart technologies, including the Internet of Things and wireless control systems, play an important role in monitoring and managing energy consumption, ventilation, lighting, and security systems of buildings. These technologies can help analyze and optimize decisions by collecting real-time data on building performance and minimize environmental impacts. Building Management Systems (BMS) with advanced capabilities enable centralized and automated control of various equipment such as heating, cooling, ventilation, and lighting systems. By utilizing artificial intelligence and machine learning, these technologies can provide optimal and economical performance based on consumption patterns and ensure building sustainability. Smart materials in building construction and design have the ability to change shape, insulate, or improve their technical properties based on environmental changes. Examples such as artificial algae, self-cleaning materials, and tunable coatings play an important role in the development of low-carbon and sustainable buildings.

Table3: Table of key criteria and technologies required for low-carbon buildings

Criterion / Technology	Description	Sample Applications	Environmental Impacts
Energy Efficiency	Use of efficient systems in energy consumption	Smart HVAC systems, Solar panels Environmental Impacts	Reduced fuel consumption and decreased CO_2 emissions
Sustainable Materials	Low-carbon and recyclable building materials Environmental Impacts	Green concrete, Durable woods	Reduction of carbon footprint during construction
Green Architectural Design Energy	Structures based on indigenous and climatic architectural principles	Natural ventilation, Proper insulation	Energy savings and reduced heating and cooling needs
Energy Production and Storage	Utilizing renewable sources and storing energy	Lithium batteries, Solar energy systems	Ensures energy sustainability over time
Smart Technologies	Centralized and automatic system control	Reduces wasteful consumption and improves efficiency	Reduces wasteful consumption and improves efficiency
Advanced Insulation	Technologies for thermal and acoustic insulation	Plastic and nano-insulation panels	Decreases the need for heating and cooling systems
Construction Technologies	Rapid and cost-effective construction techniques	Prefabricated buildings, 3D printing, BIM	Reduces waste and construction time
Water Recycling	Rainwater harvesting and purification systems Advanced	Water recycling systems, Re-treatment processes	Lowers urban water resource consumption
Impact-Free Food and Clothing Production Technologies	Biological and harmless production methods	Algae-based materials, Adaptive coatings	Reduces negative environmental effects of material production
Nanomaterials	Durable and lighter materials	Smart materials, Nano-insulation	Increases durability and reduces energy demands
Pollution Control Technologies	Filtration and equipment for clean environments	Air filters, Purification systems	Improves indoor air quality
Green Transportation Technologies	Electric charging infrastructure	Charging stations, Electric parking facilities	Decreases pollutant emissions at the building site

REFERENCES

Bakhshaei, M., & Ramezanian, M. (2020). "Waste Management Strategies for Sustainable Development in Iran." Waste Management, 98, 1-9.

Bakker, K. (2016). Tiny House, Big Impact: Environmental Sustainability. Environmental Review Journal.

Brandon, J. (2021). Living Large in Small Spaces: The Pros and Cons of Tiny Living. Journal of Urban Design.

Cameron, E. & Collins, M. (2018). Zero Carbon Housing: A Global Perspective. Routledge.

Chen, H., Wang, X., & Conforth, R. (2021). "Water Resource Management in China: A Strategic Approach." Water Resources Research, 57(3).

Dunn, R. (2019). The Tiny House Movement: A Powerful Social Change. New York: Urban Perspectives.

Emami, M. (2023). "Biodiversity Conservation Challenges in Iran." Environmental Science & Policy, 145.

Feng, J., Fu, T., & Xu, L. (2021). "Biodiversity and Climate Change: Implications for China's Zero Carbon Goals." Biodiversity Conservation, 31(5), 1071-1085.

Fischer, L., et al. (2020). "Community Engagement in Sustainable Building Projects: The Role of Education". Journal of Sustainable Development Education and Advocacy, 12(3), 45-63.

Geng, Y., Wu, Y., & Liu, Z. (2021). "Sustainability and Quality of Life in China: A Zero Carbon Perspective." Sustainable Cities and Society, 68.

Gholizadeh, M., Salehi, M., & Ranjbar, F. (2021). "Future of Zero Carbon Strategies in Iran." Renewable and Sustainable Energy Reviews, 149.

Gonzalez, A., et al. (2023). "Government Incentives for Carbon Neutral Housing: A Comparative Study". Energy Policy, 162, 112839.

He, H., Wang, Y., & Li, Q. (2021). "Energy Optimization Strategies for Industrial Sectors in China." Journal of Cleaner Production, 290.

Hosseini, M., & Mikhail, M. (2021). "Economic Impacts of Sanctions on Iran's Energy Policies." Energy Policy, 156.

Huang, Y., et al. (2022). "Integrating Urban Green Spaces into Sustainable Housing Development". Urban Ecosystem, 25, 1-10.

International Energy Agency (IEA). (2020). Solar Energy Perspectives. IEA Publications.

Ismaeil, E. M. H., & Sobaih, A. E. E. (2023). Heuristic Approach for Net-Zero Energy Residential Buildings in Arid Region Using Dual Renewable Energy Sources. Buildings, 13(3), 796. https://doi.org/10.3390/buildings13030796

Kazemi, Z., & Taheri, H. (2023). "Renewable Energy Development in Iran: Challenges and Perspectives." Renewable Energy, 196, 553-567.

Klein, K. (2014). The Minimalist Home: A Simple Approach to a Clutter-Free Life. New York: Simple Living Press.

Lehmann, S. (2013). Whole Life Cycle of Homes: Sustainability in the Residential Sector. Wiley.

Li, J. (2020). Culture and Micro-Housing: A Study in Design and Identity. Journal of Cultural Studies.

Li, Q., Wang, L., & Zhang, S. (2020). "Public Awareness of Environmental Issues in China: A Survey Study." Environmental Policy and Governance, 30(4), 229-241.

Lichtenstein, A. (2020). DIY Tiny House: Build Your Own Affordable Home. Seattle: PNW Books.

MCManus, R. (2021). Tiny Living: Community and Identity in Small Homes. Social Issues Journal.•Nourian, R., et al. (2021). "State of Renewable Energy in Iran: Policies, Challenges, and Opportunities." Energy Reports, 7, 35-46.

Nykvist, B. & Nilsson, M. (2015). "The Role of Water Management in Urban Sustainability". Environmental Science & Policy, 54, 1-10.

Pearson, S. (2009). Medieval Houses in English Towns: Form and Location. Vernacular Architecture, 40, 1 - 22.

Rattenbury, K. (2008). This Is Not Architecture: Media Constructions. New York: Routledge.• Rice, C. (2016). Sustainable Tiny Houses: A New Era of Eco-Friendly Living. San Francisco: Green Home Publishing.

Sadeghi, G., et al. (2020). "Social Challenges to Zero Carbon Goals in Iran." Sustainability, 12(21), 9060.

Sadeghi, G., et al. (2022). "Public Engagement and Environmental Policies in Iran: An Overview." Journal of Environmental Management, 309.

Smith, P. (2005). Architecture and Social Reform in the Careers of Morris and Wright. London: Ashgate.

Sundstrom, U. (2020). Tiny Homes, Big Ideas: The Social Impact of the Tiny House Movement.Routledge.

Taleghani, M., et al. (2020). "The Future of Coal in Iran: Challenges and Opportunities." Energy, 212.

Thompson, L. (2016). The Tiny House Movement and Its Impact on Society. Architecture Journal.

Wang, Y., & Zhang, Z. (2022). "Electric Vehicles in China: A Review of Recent Developments." Transporta-

tion Research Part D: Transport and Environment, 95.

Wang, Y., et al. (2020). "Smart Energy Management Systems: A Review for Future Applications." Energy Reports, 6, 9-20.

Williamson, T. (2020). "Social Sustainability in Urban Developments: An Essential Aspect of Housing". Journal of Urban Planning and Development, 146(1), 04019049.

Zare, M., & Gholizadeh, M. (2021). "Community Awareness and Participation in Environmental Issues in Iran." Community Development Journal, 57(2), 271-287.

Zhang, Y., & Zhou, X. (2022). "The Role of Renewable Energy in Achieving Carbon Neutrality in China." Journal of Cleaner Production, 299.

Zhao, R. (2019). Urban Planning and Micro-Housing Development in China. Journal of Urban Development.

Zhou, J., et al. (2021). "The Impact of Coal Phase-Out on China's Energy Transition." Energy Reports, 7, 485-492.

Zhou, X., Shou, J., & Cui, W. (2022). A Game-Theoretic Approach to Design Solar Power Generation/Storage Microgrid System for the Community in China. Sustainability, 14(16), 10021. https://doi.org/10.3390/su141610021