

City Form and Energy Resilience: A Systematic Review of Methods, Indicators, and Trends

Maryam Roosta^{a*} - Roza Vakilinejad^b - Fatemeh Norouzi^c

^a Associate Professor of Civil, Faculty of Arts and Architecture, Shiraz University, Shiraz, Iran (Corresponding Author).

^b Associate Professor of Architecture, Faculty of Arts and Architecture, Shiraz University, Shiraz, Iran.

^c Ph.D. Candidate in Architecture, College of Art and Architecture, Shiraz University, Shiraz, Iran.

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ABSTRACT

Increased urbanization, excessive energy consumption, and concerns about the depletion of energy resources, alongside climate change, have posed significant challenges commonly addressed in scientific and research communities under the concept of “energy resilience,” which has evolved from the urban resilience approach over the last two decades. Recently, the relationship between city form and energy resilience has garnered increasing attention. Reviewing recent research in this area offers comprehensive insights into the indicators of city form that affect energy resilience and sheds light on the course of future studies by analyzing the trajectory of influential research in this field. This study aims to systematically review previous research, focusing on studies published within the last decade. It seeks to identify the most important indicators, methods, and trends regarding city form and energy resilience. The methodology of this study involved several steps: first, a search in the Scopus database yielded an initial list of 413 relevant studies. Next, the PRISMA checklist was used to screen the research three times, which distilled the list to 31 studies for analysis. The selected articles were examined based on publication year, geographical origin, common conceptual areas and keywords, methodology, scale, and indicators studied. The findings highlight key indicators of city form that affect energy resilience at macro, meso, and micro scales. Additionally, the study categorizes and analyzes the methodological approaches applied and discusses current research trends. These findings can be beneficial for both academic circles, aiding graduate students and faculty members in developing research plans, and professional circles, assisting in the formulation of development and revision plans as well as the regulation of urban rules and regulations.

Keywords: City Form, Morphology, Energy Resilience, Climate Change.

* E_mail: m-roosta@shirazu.ac.ir

1. INTRODUCTION

Population growth and reduced economic opportunities in rural areas have led to rapid urbanization, a significant global trend in recent decades. This shift is closely linked to climate change and the increased consumption of natural resources, particularly energy (Ang, Berzolla, and Reinhart 2020). Currently, cities house more than half of the world's population, and this figure is projected to reach around 80% by 2030 (Dab'at and Alqadi 2024). As major centers of energy consumption and carbon emissions, management of energy consumption in urban areas becomes not only an environmental challenge but a critical necessity for achieving sustainability and reducing vulnerability to climate crises (Bansal and Quan 2022).

Given these realities, the concept of resilience has emerged in urban planning literature over the past two decades. It now extends beyond merely coping with disasters; resilience is seen as a critical quality of metropolises that must address pervasive challenges such as climate change and the energy crisis. In this context, concepts such as "energy resilient city" and "energy resilient city form" have gained traction in research since 2015. These concepts focus on the indicators of urban planning and city form that enhance energy efficiency and reduce vulnerability in this field (P.P. Yang and Quan 2016; Sharifi and Yamagata 2015; Aldieri, Gatto, and Vinci 2021; Gatto and Drago 2023).

Energy resilience holds particular significance because the building sector accounts for about 40 percent of urban energy consumption. Changes in this sector can substantially influence overall energy usage and consumption patterns. Furthermore, given the specific climatic conditions of Iran, which is predominantly arid, the need to address energy resilience locally has become increasingly urgent. Despite being one of the richest countries in oil and gas, Iran faces challenges related to excessive energy consumption and shortages, particularly during hot and cold months. Per capita urban energy consumption in Iran is approximately 285 kWh/m², more than twice that of many developing countries.

The present study aims to review existing literature and analyze the relationship between city form and energy resilience. It seeks to identify key indicators, methodologies, and concepts applied to examine energy resilience, as well as important urban morphology indicators that affect energy resilience. Additionally, it explains recent trends in research in this field. So, the central research questions are: What are the most significant methodologies and indicators addressed in previous studies concerning city form and energy resilience? What trends have dominated research in this area in recent years? The first question relates to the content dimensions, while the second pertains to the procedural dimensions of research, which will help clarify future research directions. The findings from this research can be beneficial for

both academic communities in identifying research gaps and developing domestic research in this field, and professional communities involved in urban management and planning for better decision-making. A review of the literature reveals that a substantial portion of the research published up to 2020 has investigated urban morphological indicators such as density, porosity, street aspect ratio, block size, and land use. Many studies have identified urban density as an effective factor in reducing energy consumption (Sharifi 2019; X. Liu et al. 2020). However, some studies have also pointed out its negative consequences, such as increased heat islands and decreased green spaces (Oh and Kim 2019). Furthermore, certain research has emphasized the key role of commercial use in enhancing energy efficiency (You and Kim 2018; Chen, Han, and De Vries 2020). On a macro scale, studies by Fuchs and Mills (2013) and the conceptual framework presented by Sharifi and Yamagata (2015) have suggested that city form can serve as a management tool to regulate energy consumption. On a micro scale, various modeling studies have indicated that factors such as building orientation, height density, and plan patterns affect heating and cooling needs (Perera, Javanroodi, and Nik 2021; Mangan et al. 2021; Fletcher and Mills 2013). However, research across various climates has yielded varying results; for example, green spaces increase heat loss in colder climates and reduce energy consumption in warmer climates (Chen, Han, and De Vries 2020; Leng et al. 2020).

Recent meta-analytic studies have shown that most studies have taken place in developed countries in Europe, America, and East Asia. In contrast, the share of Southwest Asian countries, especially Iran, is minimal (less than two percent) (Shoja, Pourjafar, and Tabibian 2019). Therefore, conducting a review study on the impact of city form on energy resilience can help fill this scientific gap. It can also lay the groundwork for reevaluating the current urban development patterns in Iran to better align them with the goals of sustainability and resilience.

2. THEORETICAL FOUNDATIONS

2.1. City Form and its Indicators

The concepts "city form" and "urban morphology" are sometimes used interchangeably, making it essential to examine them as distinct concepts.

City form and urban morphology are two close but distinct concepts. Urban morphology focuses on the physical and historical evolution of cities' structures, including elements such as buildings, plots, and street networks (Marshall and Çalişkan 2011), while city form encompasses spatial patterns, land use, density, and the organization of spaces in addition to physical features (Leng et al. 2020; Rostami, Nasrollahi, and Khodakarami 2024). City form is not merely a passive reflection of urban development; it is also

a determining factor in shaping citizen behavior, travel patterns, public health, and environmental efficiency. Key indicators of city form include size, shape, intensity, spatial distribution, diversity, and connectivity, which can be analyzed at various scales (building, block, neighborhood, and city) (Tümtürk, Karakiewicz, and de Haan 2024; Xing et al. 2024; Ji et al. 2022; Jianqi Li and Li 2024).

The systemic boundary of city form refers to its physical form, which includes the geometric features of buildings and landscape elements. Geometric features encompass the shapes and layouts of buildings, while landscape elements include land use and vegetation. However, this boundary can be expanded to incorporate functional and socio-economic factors, making city form a complex urban system (Quan and Li 2021).

Jianqi Li and Li (2024) categorized city form indicators into six groups across macro, meso, and micro scales: size, shape, spatial distribution, intensity, connectivity, and diversity. Size, shape, and intensity indicators can be measured directly at the individual building level, while other indicators require quantification at larger scales, such as streets and blocks.

2.2. Energy Resilience and City Form

The concept of energy resilience has emerged as a response to crises posed by climate change and increasing energy demand. Energy resilience goes beyond just recovering from shocks; it also involves reducing vulnerability, proactively adapting, and enhancing energy system performance during disruptions (Ping et al. 2025). Gatto and Drago (2023) have defined urban energy resilience as a city's capability to adapt to energy disruptions and to anticipate and recover from them. This approach focuses on quantifying indicators, thus enabling the analysis and comparison of different urban patterns. Sharifi and Yamagata (2015) have described energy resilience as encompassing a range of measures for preparation, absorption, recovery, and adaptation that ensure the availability, affordability, and utility of energy supply, transmission, and distribution over time. This establishes a theoretical framework for linking city form and energy resilience, which allows for the analysis of how urban design and physical patterns influence energy consumption, productivity, and the sustainability of cities (Yang and Quan 2016). The most significant keyword in the studies on energy resilience in cities is "energy efficiency." Research in this area has examined energy efficiency

at various scales through case simulations or theoretical foundations and expert opinions, yielding explanatory, evaluative, or strategic frameworks (Sharifi and Yamagata 2015; Gatto and Drago 2023; Aldieri, Gatto, and Vinci 2021; Yang 2015).

In urban energy resilience policymaking, it is crucial to consider how city form affects energy consumption, along with other measures such as renovating building materials, upgrading heating systems, improving ventilation, and adjusting pricing (Quan and Li 2021). A large part of energy consumption (on average 80 percent) is associated with the direct effects of different city forms (Zhao et al. 2024). City form affects building energy consumption both directly and indirectly. This interplay can affect how much heat is absorbed from solar radiation and alter the overall energy consumption patterns within a city. The building energy performance varies with the geometric characteristics of nearby buildings and the intensity of solar radiation in the study areas (K. Liu et al. 2023). Therefore, to understand the indicators of city form that affect energy resilience across various contexts and sub-climates, it is necessary to replicate, develop, and review prior studies in this field.

3. METHOD

The present study aims to examine the concepts of city form and energy resilience, as well as their relationship, by reviewing the indicators of city form that affect energy resilience. The data were collected in two steps by reviewing existing studies on city form and energy resilience in the Scopus database:

1. To identify: This step involved searching for topics and abstracts, resulting in an initial list of 413 studies. The following keywords and terms were used for the search: (Energy) AND ("resilience" OR "resilient") AND ("urban" OR "city") AND ("form" OR "morphology" OR "geometry").

2. To screen: The first stage of screening focused on articles from peer-reviewed journals published in English. Only research articles and review studies were selected, narrowing the initial list to 235 articles. In the second stage, limiting the subject area and examining titles reduced the total number of articles to 222. The third stage applied a critical look to study the abstracts in more detail, which led to the identification of studies that have addressed energy resilience and its relationship with city form, ultimately distilling the list to 31 articles for the systematic review. This process followed the PRISMA framework, as illustrated in Figure 1.

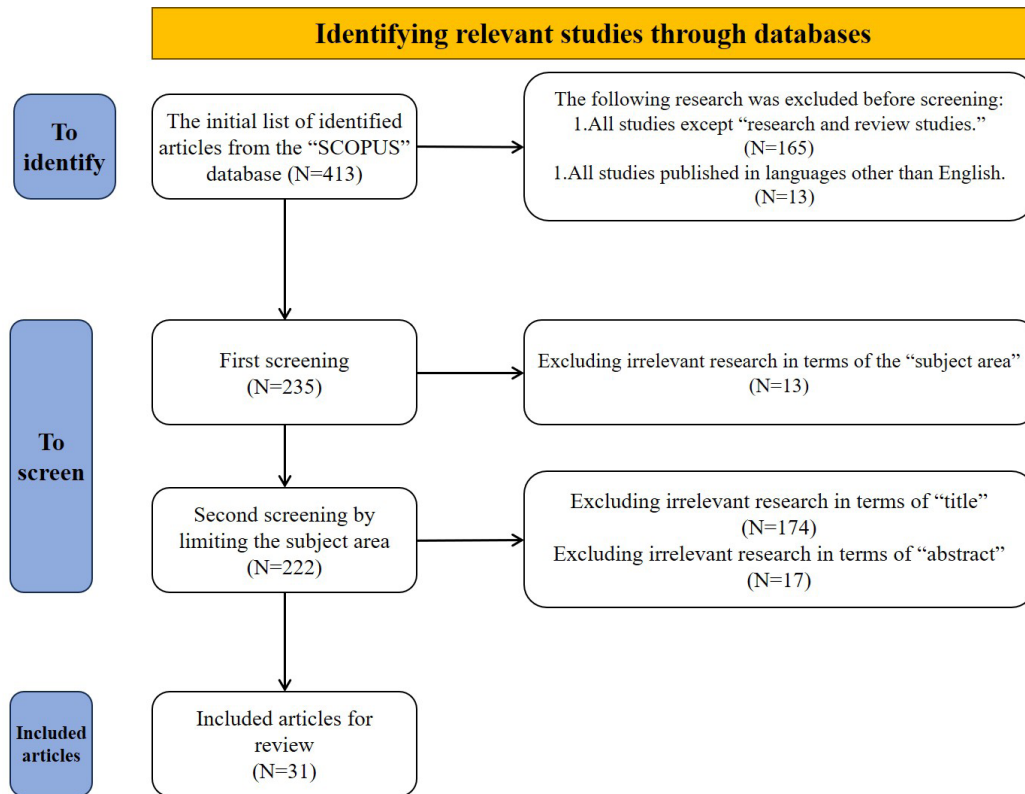


Fig. 1. PRISMA Framework for Selecting Final Articles for Systematic Review

4. FINDINGS

4.1. Publication Year

As seen in Figure 2, the number of articles indicates

an upward trend since 2006, peaking in 2025 with a publication rate of 29 percent.

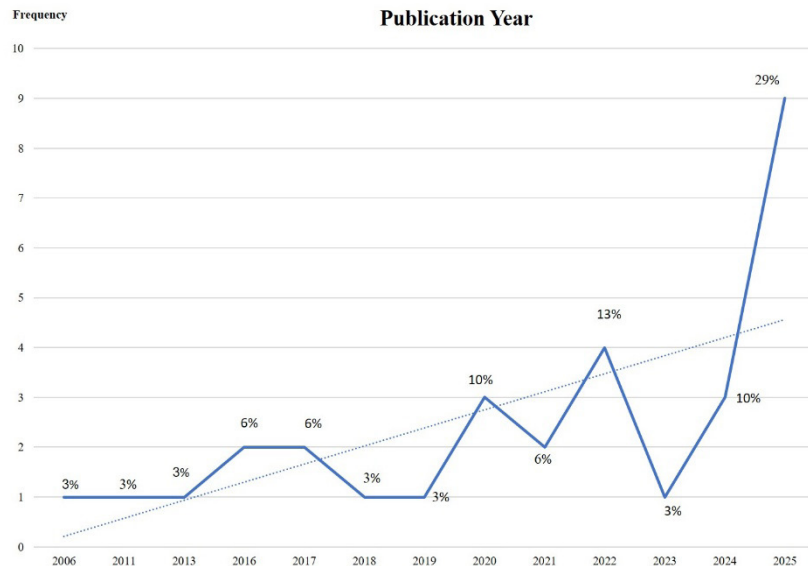


Fig. 2. Frequency of Reviewed Articles by Publication Year

4.2. Geographical Origin

As illustrated in Figure 3, the majority of the articles studied pertained to Asian countries, followed by

American and European countries, respectively. Figure 4 displays the frequency of research by country.

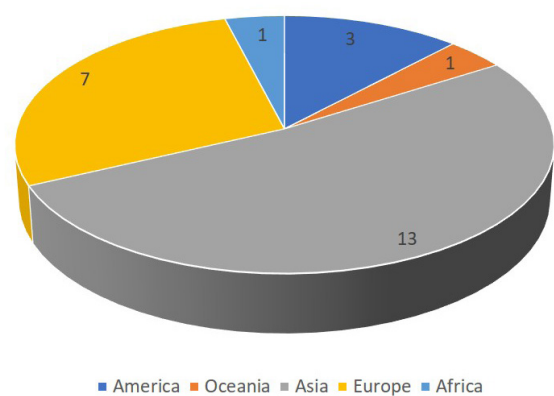


Fig. 3. Frequency of Selected Research by Continent

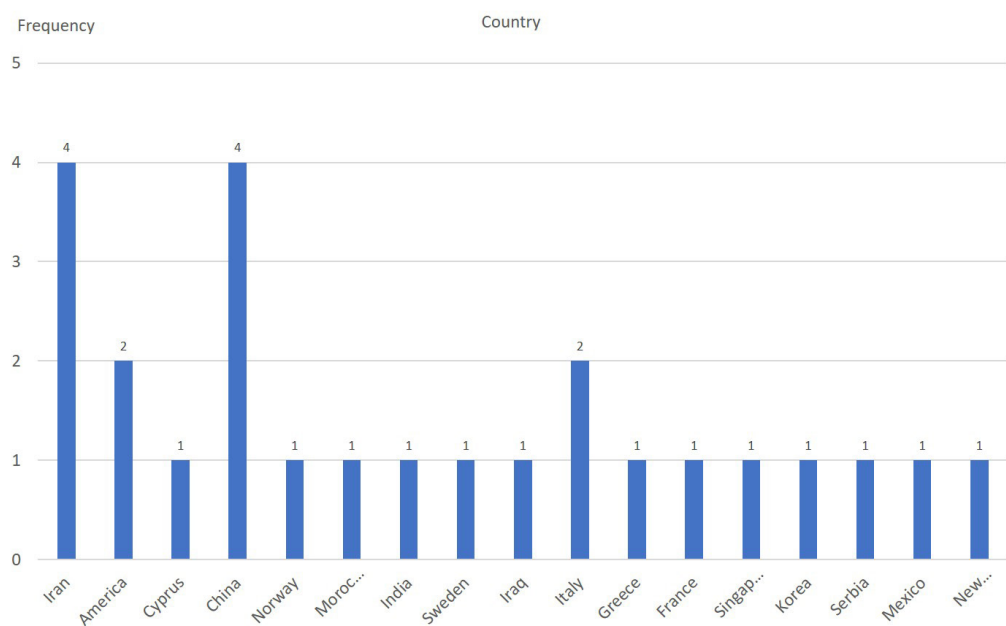


Fig. 4. Frequency of Selected Research by Country

4.3. Scales Studied

As shown in Figure 5, most of the research reviewed was conducted at the meso scale (neighborhoods and

urban areas), followed by the macro scale (the entire city) and micro scale (blocks and plots), respectively.

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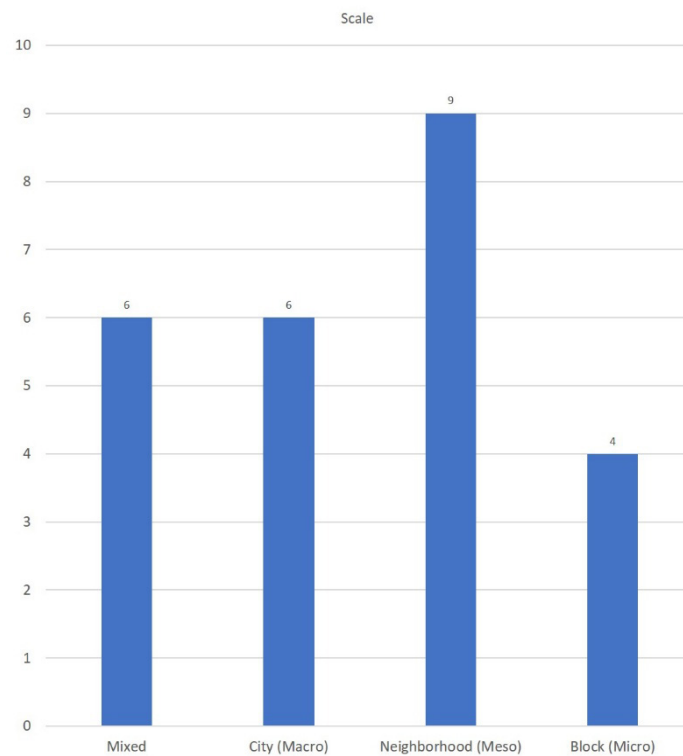


Fig. 5. Frequency of Selected Articles by Scale

Table 1. Frequency of Selected Articles by Scale

Scale	Frequency	Percent	Articles
Mixed	6	24	(Vurro et al. 2025; Bian et al. 2025; Hosseini et al. 2025; Shi et al. 2025; Javanroodi et al. 2022; Wang et al. 2020)
Macro	6	24	(X. Li et al. 2023; Mohabat Doost et al. 2020; Lazarević, Keković, and Antić 2018; Khan and Pinter 2016; Saunders, Dantas, and Krumdieck 2006; Dieleman 2013)
Meso	9	35	(Seelig 2011; Yuan et al. 2020; Esfandi et al. 2022; Palusci et al. 2022; Basee and Abdulla 2022; Bhavsar, Sharma, and Kapadia 2024; Rachidi and Mounir 2025; Rezaeirad, Pouramin, and Afzali 2025; Kostourou 2021)
Micro	4	16	(Najian and Goudarzi 2025; Xu et al. 2024; Perera, Javanroodi, and Nik 2021; Lee and Jeong 2017)

4.4. Common Conceptual Areas and Keywords

Figure 6 illustrates the word cloud generated from the articles reviewed, highlighting the most frequently searched common terms. It indicates “urban planning” and “urban design” as the two main areas of knowledge represented in the articles. Other frequently used concepts include “urban morphology,”

which examines city form, and mediating concepts such as “Climate change,” “microclimate,” and “climate resilience,” which are significant in the fields of energy resilience and energy efficiency. The parameters “air temperature” and “wind,” as the main variables in the field of thermal comfort, are noted as influential mediating variables in the articles on energy.



Fig. 6. Word Cloud and Common Conceptual Areas in Selected Articles

4.5. Methodology

In general classification, as illustrated in Figure 7, more than 80 percent of the articles reviewed were scientific research articles employing empirical and semi-empirical approaches, while about 20 percent applied a theoretical review approach. Review articles were developed to formulate theoretical frameworks aimed at enhancing energy resilience in the urban system (Javanroodi et al. 2022). Some of these frameworks employed artificial intelligence (AI) and machine learning (ML) tools (Marey et al. 2025).

A closer examination reveals that the most frequently used methods included simulation techniques with scenarios, field studies, and spatial data layering using tools like GIS. Additionally, review studies, analytical and statistical assessments, and numerical modeling were commonly applied. Among numerical and quantitative models, the Weather Research and Forecasting (WRF) model and Building Energy Model (BEM)/Building Energy Parameterization (BEP) model were most frequently used to predict climate parameters and energy consumption (Vurro et al. 2025; Wang et al. 2020). Other frequently utilized models included the Urban Weather Generator (UWG) (Shi et al. 2025; Rachidi and Mounir 2025) and machine learning-based models (Bian et al. 2025).

In some cases, computational fluid dynamics (CFD) models were used to explore how variables like wind and ventilation impact energy consumption (Palusci et al. 2022; Najian and Goudarzi 2025). Javanroodi

et al. (2022) combined CFD and neural networks to describe microclimatic boundary conditions and the effect of morphology on energy consumption in this field.

Regarding software and plugins for visual simulation, notable mentions include Grasshopper (Bhavsar, Sharma, and Kapadia 2024), Rhino, Biomorpher (Bhavsar, Sharma, and Kapadia 2024), and EnergyPlus (Shi et al. 2025). In their study, Baathi and Abdulla (2022) utilized DepthMap software and space syntax to analyze the relationship between configuration and energy consumption (Basee and Abdulla 2022).

Analytical and statistical studies frequently employed fuzzy techniques such as the Analytic Network Process (ANP) (Esfandi et al. 2022) and statistical tests like regression and correlation (Khan and Pinter 2016; Lee and Jeong 2017).

Many studies also utilized mixed methods to meet their objectives. For instance, one common approach involved correlating and regressing satellite data on ground temperature, city form, and energy consumption (Rezaeirad, Pouramin, and Afzali 2025). In a study that examined 18 urban areas in Hong Kong, various form indicators were localized using GIS layers. Next, statistical data on mediating variables such as urban heat islands, ground surface temperature, carbon emissions, and energy consumption were collected to develop a model that explained the internal relationships between these variables using AI and ML tools (Bian et al. 2025).

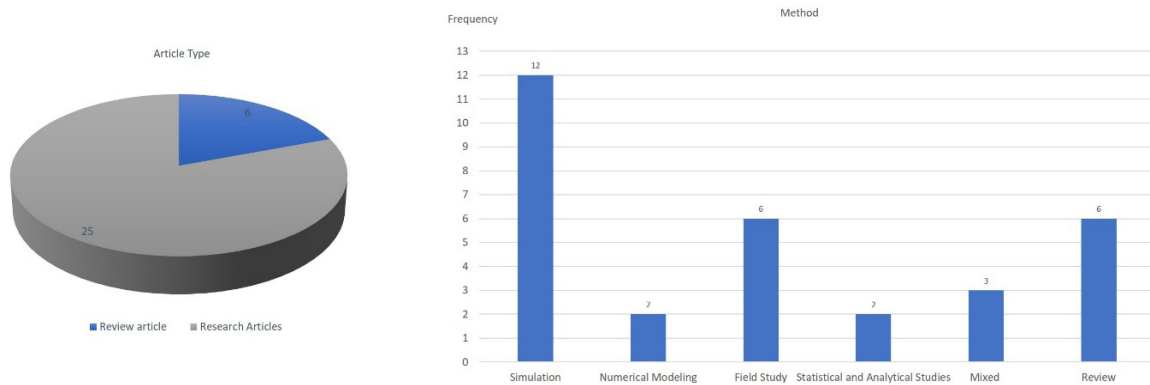


Fig. 7. Frequency of Selected Articles by Methodology

4.6. Indicators of City Form that Affect Energy Resilience in the City

The primary objective of this study is to identify and classify the indicators of urban form that influence energy consumption. To achieve this, qualitative content analysis was conducted to extract influential indicators from prior research. The extracted indicators were initially categorized into three scales: micro, meso, and macro, based on conventional classifications of city form indicators. Due to the significant overlap between macro- and meso-scale indicators (zone scales), they were analyzed collectively. It's important to note that Tables 2 and 3 do not include indicators that appeared in fewer than three studies.

- Meso and macro scales

As illustrated in Table 2 and Figure 8, density and compactness emerged as the most frequently cited indicators at the city and urban area scales in previous studies. There are differing views on the relationship between density and energy consumption in buildings. Many researchers suggest that this relationship is complex and varies across different areas (Quan and Li 2021). A study conducted in Rome revealed that at the urban neighborhood scale, both building height and density are correlated with the mediating indicator of ventilation; increasing building height and density leads to reduced ventilation at the pedestrian level and higher energy consumption (Palusci et al. 2022). Other studies have found that increased density can result in lower energy consumption (Rostami, Nasrollahi, and Khodakarami 2024; Leng et al. 2020; X. Liu et al. 2020). However, building density can increase energy demand by up to 27% (Perera, Javanroodi, and Nik 2021). Conversely, Zhao et al. (2024) demonstrated that reducing building density plays a significant role in mitigating the urban heat island effect. Another study in Copenhagen indicated that building density affects natural lighting and the amount of solar energy received by buildings. This increased density can result in energy consumption for lighting, cooling, and heating by up to 30% for

office buildings and 19% for residential units (Leng et al. 2020).

Regarding height, another commonly studied indicator, findings vary, highlighting the necessity to research this factor across individual climatic areas. Studies show that building height impacts cooling demand by 7.3% to 8.6% and heating demand by 13.6% to 31.2% (Xie et al. 2023). Generally, taller buildings may reduce energy consumption due to a lower percentage of floor space impacted by cross-shading and changes in the surface/volume (S/V) ratio (Bansal and Quan 2022). However, research in Wuhan indicated a weak positive correlation between building height and energy consumption, suggesting that taller structures may require more energy, potentially due to higher demands for elevators and heating, ventilation, and air conditioning (HVAC) systems (Du et al. 2025).

Vegetation and green spaces are also frequently cited indicators at the zone scale, with areas featuring higher vegetation cover correlating with lower energy consumption (Dab'at and Alqadi 2024). Vegetation helps reduce cooling loads during summer (Rostami, Nasrollahi, and Khodakarami 2024).

At the macro scale, the geometric and morphological patterns of urban contexts are critical indicators. Research indicates that optimized urban morphology at the macro and meso scales can lower the levelized cost of energy infrastructure by up to 30% (Perera, Javanroodi, and Nik 2021). A study by Hosseini et al. (2025) in Norway highlighted the role of clustering patterns in decreasing energy consumption and costs. Rashidi and Mounir (2025) compared traditional (organic) and contemporary urban forms in Morocco, weighing their advantages and disadvantages concerning energy consumption. Baathi and Abdulla (2022), in their research in Baghdad, examined how modifying traditional structures in historical cities impacts various dimensions of resilience, including energy efficiency, suggesting that such changes could increase vulnerability by weakening internal connections.

The sky exposure factor, along with other indicators

related to aspect ratios, is frequently examined at both macro and meso scales, affecting street network characteristics. This factor directly influences surface temperature, solar radiation absorption, natural

ventilation, and night cooling. Generally, a higher sky exposure factor can diminish cooling loads, although it may intensify nighttime heat (Najian and Goudarzi 2025).

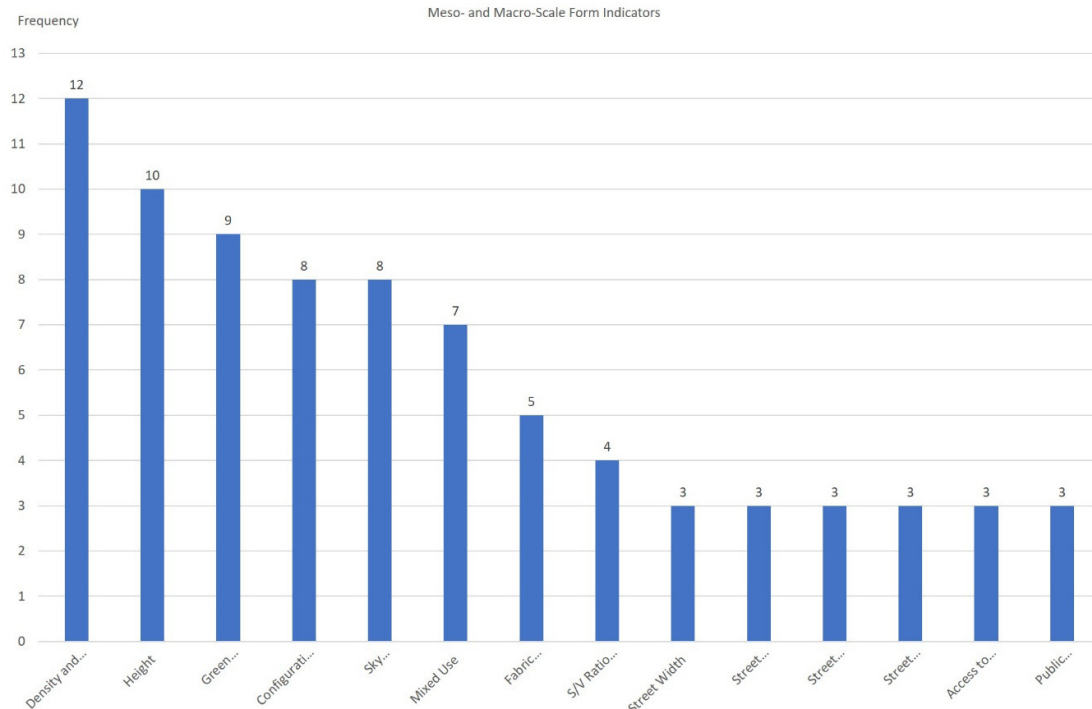


Fig. 8. Frequency of Selected Studies by Form Indicators at Meso and Macro Scales

Table 2 presents the most frequently used indicators on meso and macro scales in the selected studies. As shown in the lower rows of the table, along with physical indicators, functional indicators of urban

form, such as mixed use, access to urban services, and public transportation, have also been included in the reviewed studies.

Table 2. Frequency of Selected Studies by Form Indicators at Meso and Macro Scales

Indicator		Articles	Frequency
1	Configuration and Geometry of the Fabric	(Hosseini et al. 2025; Javanroodi et al. 2022; Perera, Javanroodi, and Nik 2021; Sharifi and Yamagata 2016; Rachidi and Mounir 2025; Bhavsar, Sharma, and Kapadia 2024; Esfandi et al. 2022; Schoeman 2016)	8
2	Fabric Orientation	(Bian et al. 2025; Sharifi and Yamagata 2016; Javanroodi et al. 2022; Rachidi and Mounir 2025; Bhavsar, Sharma, and Kapadia 2024)	5
3	Sky Exposure Factor	(Javanroodi et al. 2022; Bian et al. 2025; Sharifi and Yamagata 2016; Rachidi and Mounir 2025; Bhavsar, Sharma, and Kapadia 2024; Marey et al. 2025; Javanroodi et al. 2023; Najian and Goudarzi 2025)	8
4	Green Space/ Vegetation	(Vurro et al. 2025; Shi et al. 2025; Bian et al. 2025; Y. Wang et al. 2020; Rachidi and Mounir 2025; Esfandi et al. 2022; Marey et al. 2025; Rezaeirad, Pouramin, and Afzali 2025; Lee and Jeong 2017)	9
5	Building Density and Compactness	(Shi et al. 2025; Bian et al. 2025; Vurro et al. 2025; Perera, Javanroodi, and Nik 2021; Khan and Pinter 2016; Sharifi and Yamagata 2016; Bhavsar, Sharma, and Kapadia 2024; Marey et al. 2025; Rezaeirad, Pouramin, and Afzali 2025; Lee and Jeong 2017; Kostourou 2021; Xu et al. 2024)	12
6	Height	(Rachidi and Mounir 2025; Marey et al. 2025; Javanroodi et al. 2022; Lee and Jeong 2017; Wang et al. 2020; Vurro et al. 2025; Bian et al. 2025; Perera, Javanroodi, and Nik 2021; Shi et al. 2025; Palusci et al. 2022)	10

	Indicator	Articles	Frequency
7	Surface Area/Volume Ratio (Total Built-up Area)	(Lee and Jeong 2017; Y. Wang et al. 2020; Perera, Javanroodi, and Nik 2021; Yuan et al. 2020)	4
8	Street Width	(Rezaeirad, Pouramin, and Afzali 2025; Wang et al. 2020; Bian et al. 2025)	3
9	Street Orientation	(Bhavsar, Sharma, and Kapadia 2024; Wang et al. 2020; Lee and Jeong 2017)	3
10	Street Connectivity	(Wang et al. 2020; Sharifi and Yamagata 2016; Basee and Abdulla 2022)	3
11	Street Integration	(Wang et al. 2020; Sharifi and Yamagata 2016; Basee and Abdulla 2022)	3
12	Mixed Use	(Bhavsar, Sharma, and Kapadia 2024; Schoeman 2016; Esfandi et al. 2022; Perera, Javanroodi, and Nik 2021; Sharifi and Yamagata 2016; Mohabat Doost et al. 2020; Saunders, Dantas, and Krumdieck 2006)	7
13	Access to Urban Services	(Schoeman 2016; Esfandi et al. 2022; Saunders, Dantas, and Krumdieck 2006)	3
14	Public Transportation	(Schoeman 2016; Esfandi et al. 2022; Saunders, Dantas, and Krumdieck 2006)	3

- Micro scale

Table 3 outlines the indicators of city form that influence energy resilience at the microscale, summarized in Figure 9 for comparison. These indicators analyze city form at both the block and plot scales. One of the most frequently cited indicators is the total floor area, which significantly affects solar radiation absorption, ventilation, shading, heat transfer, and the urban heat island effect, all of which contribute to energy consumption (Esfandi et al. 2022; Lee and Jeong 2017; Perera, Javanroodi, and

Nik 2021). Typically, lower levels of this indicator increase the surface area exposed to radiation, leading to higher cooling energy demands. In contrast, higher levels can reduce the cooling load through shading and decreased direct radiation (Bian et al. 2025; Xu et al. 2024). However, elevated floor areas can hinder ventilation and promote heat accumulation in hot-humid and arid climates, resulting in increased nighttime temperatures and greater overall energy consumption (Perera, Javanroodi, and Nik 2021).

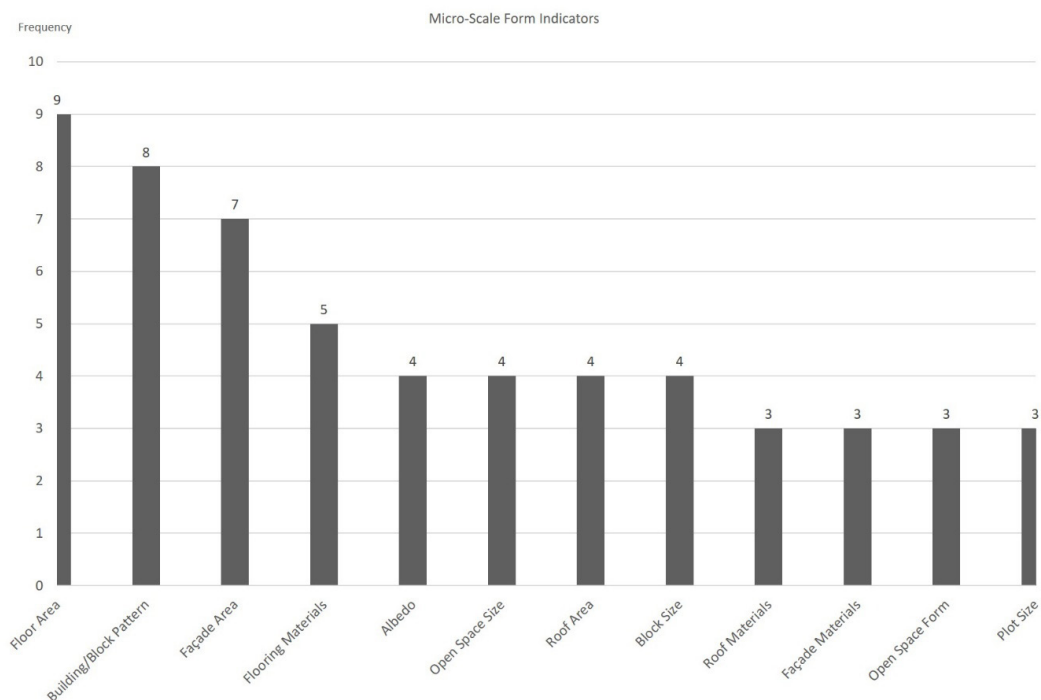


Fig. 9. Frequency of Selected Studies by City Form Indicators at the Micro Scale

The building form pattern is another frequent micro-scale indicator in the study of energy resilience. Identifying the optimal form pattern necessitates thorough research tailored to each sub-climate

and geographical context. For example, in the hot summer Mediterranean climate, the courtyard pattern is considered. For example, in the hot summer Mediterranean climate, the courtyard pattern is

considered optimal for energy consumption (Rachidi and Mounir 2025). Also, the central courtyard pattern can significantly reduce heat accumulation within a block, thereby improving natural ventilation within the interior and lowering energy consumption (Wang

et al. 2021). A study in Wuhan, China, revealed that buildings designed with pavilions, north-south stepped plans, and varying heights in the east-west direction could collectively benefit energy consumption and other environmental variables (Xu et al. 2024).

Table 3. Frequency of Selected Studies by Form Indicators at the Micro Scale

	Indicator	Article	Frequency
1	Open Space Size	(Bhavsar, Sharma, and Kapadia 2024; Kostourou 2021; Wang et al. 2020; Lee and Jeong 2017)	4
2	Open Space Form	(Bhavsar, Sharma, and Kapadia 2024; Javanroodi et al. 2023; Lee and Jeong 2017)	3
3	Block Size	(Bian et al. 2025; Sharifi and Yamagata 2016; Palusci et al. 2022; Khan and Pinter 2016)	4
4	Plot Size	(Bian et al. 2025; Sharifi and Yamagata 2016; Palusci et al. 2022)	3
5	Floor Area	(Bian et al. 2025; Javanroodi et al. 2022; Javanroodi et al. 2023; Perera, Javanroodi, and Nik 2021; Lee and Jeong 2017; Marey et al. 2025; Rezaeirad, Pouramin, and Afzali 2025; Esfandi et al. 2022; Xu et al. 2024)	9
6	Albedo	(Sharifi and Yamagata 2016; Y. Wang et al. 2020; Marey et al. 2025; Rachidi and Mounir 2025)	4
7	Flooring Materials	(Bian et al. 2025; Perera, Javanroodi, and Nik 2021; Wang et al. 2020; Marey et al. 2025; Rezaeirad, Pouramin, and Afzali 2025)	5
8	Façade Area	(Lee and Jeong 2017; Javanroodi et al. 2022; Perera, Javanroodi, and Nik 2021; Sharifi and Yamagata 2016; Wang et al. 2020; Marey et al. 2025; Yuan et al. 2020)	7
9	Façade Materials	(Lee and Jeong 2017; Bian et al. 2025; Perera, Javanroodi, and Nik 2021)	3
10	Roof Materials	(Lee and Jeong 2017; Bian et al. 2025; Perera, Javanroodi, and Nik 2021)	3
11	Roof Area	(Javanroodi et al. 2023; Lee and Jeong 2017; Sharifi and Yamagata 2016; Wang et al. 2020)	4
12	Building or Block Pattern	(Bhavsar, Sharma, and Kapadia 2024; Javanroodi et al. 2023; Lee and Jeong 2017; Bian et al. 2025; Javanroodi et al. 2022; Perera, Javanroodi, and Nik 2021; Palusci et al. 2022; Xu et al. 2024)	8

- Mediating indicators and variables

In addition to the aforementioned city form indicators, many selected articles have addressed other indicators and variables that measure the effects of form indicators either indirectly or concurrently. Some studies have developed models to predict behavior under “boundary climatic conditions” (Javanroodi et al. 2022). Recent research has placed special emphasis on microclimates, particularly in assessing the impact of form on energy consumption within local climatic contexts (Javanroodi et al. 2022). Key temperature-related indicators, such as daytime and nighttime temperatures (Wang et al. 2020; Rezaeirad, Pouramin, and Afzali 2025; Lee and Jeong 2017), heat stress and strain (Palusci et al. 2022; Vurro et al. 2025), and thermal comfort (Bian et al. 2025; Xu et al. 2024) are among the most frequently utilized indicators (Marey et al. 2025). Additionally, some studies, particularly in high-rise urban areas, have examined how “heat islands” influence the relationship between form and energy resilience (Bian et al. 2025; Rachidi and Mounir 2025; Yuan et al. 2020).

Air pollution, carbon emissions, and greenhouse gas levels were among other indicators examined concurrently. Among the climatic indicators,

humidity, wind effects, and ventilation across varying states, especially in arid and hot-humid climates, were examined as mediating variables (Marey et al. 2025; Palusci et al. 2022; Lee and Jeong 2017).

For example, the article by Najian and Goudarzi (2025) concentrated on the effect of form on wind dynamics at the pedestrian level. Given the local climatic characteristics, it seems necessary to incorporate these mediating variables when developing research plans in this field.

5. DISCUSSION

The trajectory of research on city form and resilient energy over the last two decades reveals a shift from using linear, unidimensional approaches to more multidimensional and complex methodologies. This shift is reflected in both research design and the attention given to various components and mediating variables, as well as in the hybrid methodological approaches that have gained traction in recent years, particularly in reputable journals. It is important to recognize that both resilience and city form are dynamic, multifaceted, and complex in nature. To explain the findings of their review study, Sharifi

and Yamagata (2016) emphasized that examining relationships between the components of the resilience framework shows that decisions related to one component can significantly impact other components. This highlights the interconnectedness and complexity of energy resilience as a synergistic concept, underscoring the importance of adopting a systemic approach to enhance it.

The trajectory of research also indicated that recent studies have incorporated mediating and influential variables such as radiation, humidity, temporal temperature, thermal comfort, heat islands, ventilation, and so on. This suggests an increasing focus on the reality and complexity of the relationship between city form and energy resilience. For instance, Bian et al. (2025) studied 18 urban areas in Hong Kong, examining the internal relationships among more than 10 form indicators, alongside data related to heat islands, heat stress, carbon emissions, and energy consumption. Similarly, Xu et al. (2024) examined over 40 form prototypes across 114 blocks in Wuhan, China, addressing thermal comfort and mediating climatic variables in their investigation of the relationship between city form and energy resilience. In these approaches, it is crucial to consider the trade-offs or co-benefits of indicators in different areas in the climate study. Many researchers have explored the simultaneous positive and negative impacts of multiple areas, seeking to find a mediator to balance energy resilience, climate comfort, carbon emissions, heat islands, and more (Bian et al. 2025; Javanroodi et al. 2022; Xu et al. 2024). As Bian et al. (2025) noted, there has been limited optimal examination of multiple climate and energy consumption criteria and their interrelationships; most studies have treated aspects such as energy consumption, urban heat island intensity, solar potential, indoor thermal comfort, and carbon emissions separately or with linear and bidimensional models, failing to leverage three-dimensional morphological features in a multi-objective and integrated optimization context.

Overcoming the limitations of traditional methods and utilizing new interdisciplinary approaches, particularly AI and ML, are also significant trends in this field of research. These technologies have shown promise in developing computational and analytical models that explain predictive patterns in energy resilience and microclimate. It seems that the integration of AI and machine learning techniques has contributed to anticipating the relationship between microclimate and energy resilience by providing scalable, efficient, and accurate predictions. Marey et al. (2025) emphasized the effective application of models such as convolutional neural networks (CNNs), long short-term memory (LSTM) networks, and hybrid frameworks, highlighting their potential in explaining the non-stationary interactions among urban morphology, energy resilience, and microclimate factors. Javanroodi et al. (2022 and 2023), in their

research in Western Europe, Furthermore, Javanroodi et al. (2022, 2023) observed the necessity for deeper insights into the intricate interactions between city form, energy consumption, and other microclimate indicators, leveraging emerging opportunities through big data and advanced technologies like AI and machine learning. Algorithms such as random forests, support vector machines, and artificial neural networks have been widely employed to predict building energy consumption, urban heat island intensity, and renewable energy generation. For example, Jianyi and Li (2024) quantified 26 morphological indicators affecting building energy consumption using proximity criteria and SHapley Additive exPlanations (SHAP), elucidating the effective and adaptive characteristics of different building types. Jianyi Li et al. (2025) combined graph neural networks (GNN) with a genetic algorithm (GA) to optimize peak-hour carbon emissions in Shanghai through improvements in city form. Liu et al. (2024) utilized SHAP to explore the nonlinear effects of built environment attributes on urban heat resilience in Beijing. Okumus and Akay (2025), as well as Jianyi Li et al. (2025), demonstrated the regional nonlinear effects of morphological criteria—such as land area ratio and street network structure—on urban heat and carbon emissions using geographically weighted regression models (XGBoost-SHAP). These learning-based approaches generally offer higher prediction accuracy compared to traditional statistical models and serve as a milestone in recent research trends in this field.

Another notable approach in analyzing the trajectory of research and current trends in this field is the incorporation of microclimate data into calculations. Recent studies tend to avoid relying on macroclimatic conditions and instead include microclimate data into numerical and statistical models or simulations (Yuan et al. 2020; Lee and Jeong 2017). In addition to the identification of a methodological gap in urban energy consumption models, Javanroodi et al. (2022) have proposed two data-driven models that downscale climate variables from meso- to microscale across various urban morphologies, particularly focusing on extreme weather conditions. Additionally, the results of examining the same indicators within different microclimates reveal that they do not produce uniform outcomes. This highlights the need for research to be repeated in various local contexts and at micro scales, employing contextual approaches in this field.

When analyzing influential meso- and macro-scale indicators of city form, it becomes apparent that achieving an optimal level of urban density and compactness is generally linked to a reduction in energy demand. This optimal level differs based on geographical and climatic contexts, which necessitates local research. Such strategies increase energy efficiency by raising the number of residents and households per unit area. Moreover, increasing

shading in the context and implementing strategies such as strategically locating land uses improve accessibility and promote pedestrianization, ultimately reducing overall energy consumption (Rostami, Nasrollahi, and Khodakarami 2024; Sharifi 2019). Alongside adopting compactness strategies, it is crucial to consider the adequate provision of infrastructure, especially public transportation, as well as high-quality urban green and open spaces, ensuring that at least a minimum per capita standard is met. On a macro scale, it is also important to focus on appropriate development patterns within the urban context. Polycentric and multi-core patterns enhance the resilience of urban fabric, not only in the energy sector but also against various natural and man-made disasters and crises (Sharifi 2019; Liu, Wang, and Bai 2024). These polycentric structures, by mitigating the urban heat island effect, also enhance accessibility and support pedestrian-oriented patterns, along with active and public transportation, which further lowers energy consumption. In discussing urban networks, factors like sky exposure and street orientation frequently emerge as the most frequent indicators in the field of energy consumption and thermal comfort within urban environments (Du et al. 2025).

At the micro level, the orientation of buildings and plot shapes significantly affects energy demand. Several studies (Huang et al. 2024; Rostami, Nasrollahi, and Khodakarami 2024) have confirmed that a north-south orientation results in the lowest total energy consumption due to a balanced distribution of solar radiation, while an east-west orientation often increases cooling loads. Conversely, complex and irregular building forms increase the surface area exposed to the external environment, leading to greater energy losses. More compact and courtyard-type designs, which have lower surface area-to-volume ratios, demonstrate higher energy efficiency (Natanian and Wortmann 2021).

The most critical research gap in understanding the relationship between city form and energy, along with recommendations for future research—particularly on a local scale—can be framed in two main aspects: content and procedure. From a content perspective, it is vital to adopt multidimensional approaches that examine the relationship between urban form and energy resilience against the complex backdrop of climate issues. This includes considering synergies and potential conflicts in striving for these goals, which traditional, linear approaches overlook. Emphasizing research that is repeated across different microclimates using microscale data—rather than generalized macroregional climate data—is crucial for enhancing research accuracy and applicability.

Regarding the procedural aspect, it is essential to adopt new methodologies, particularly numerical machine learning-based models, through interdisciplinary research. Traditional methods face numerous

limitations, underscoring the need for innovative methodological approaches, tools, and models in this field. We must take a deep, systematic approach that considers the dynamic and complex realities of urban form and resilience.

6. CONCLUSION

The present study aimed to identify the most important indicators, methods, and trends in research on urban form and energy resilience by systematically reviewing previous research, particularly those published in the last decade. To achieve this, we utilized the PRISMA framework to screen relevant articles, resulting in the selection of 31 studies. We examined these selected studies based on their publication year, geographical origin, scale, methodology, common conceptual areas and keywords, as well as influential indicators.

A review of existing research on how urban form affects energy consumption patterns reveals several key issues: First, the relationship between urban form indicators and energy consumption is not linear; it depends on contextual conditions, the type of energy (cooling or heating), climate type, and various physical-spatial attributes. Consequently, when developing research plans in this area, it is crucial to consider the multidimensionality of energy resilience, as well as the different layers of urban form and mediating climatic variables. Second, related to the first point, urban form influences energy consumption at a local level, suggesting that research in this area cannot be generalized on a broader scale. Climate science also supports the significance of microclimates and their effects on research outcomes. Third, it is especially important to apply new methods, particularly machine learning and interdisciplinary numerical models, to obtain more accurate and comprehensive results. Traditional methods are often insufficient for analyzing the multidimensional relationships and complexities involved in this field. Recent research findings indicate that these new methods have significant potential to elucidate the relationships between urban form and energy resilience, and to develop evaluation and predictive models.

The insights gained from this research can benefit graduate students and academic researchers in formulating research plans, leading to a deeper and more accurate understanding of the relationship between urban form and energy resilience within educational contexts. Additionally, the framework we presented, outlining the indicators of urban form that affect energy resilience, can be utilized by professional communities and decision-makers engaged in urban planning and management. This framework can aid in formulating development plans, redesigning existing urban areas, and establishing executive rules and regulations.

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CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

MORAL APPROVAL

The authors commit to observe all the ethical principles of the publication of the scientific work based on the ethical principles of COPE. In case of any violation of the ethical principles, even after the publication of the article, they give the journal the right to delete the article and follow up on the matter.

PARTICIPATION PERCENTAGE

The authors state that they have directly participated in the stages of conducting research and writing the article.

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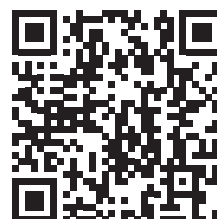
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