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Original Article

Planning Pathways Towards Zero-Energy Urban Development in Hot and Dry Climates: A Simulation-Based Study of Semnan, Iran

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Abstract
Purpose- This study investigates how building-level energy-efficiency and solar-energy measures can inform planning pathways toward zero-energy urban development in hot and dry climates, using Semnan, Iran, as a case study.
Design/methodology/approach- This applied study adopts a quantitative, simulation-based approach. A single-story residential case-study building with a floor area of 260 m² in Semnan was modeled using DesignBuilder and the EnergyPlus simulation engine. First, the annual energy consumption of the building was estimated under the baseline condition. Subsequently, selected energy-efficiency and solar-energy strategies, including improved glazing and the use of solar energy, were incorporated into the building model, and the resulting energy performance was compared with the baseline scenario. The simulation results were then interpreted to identify their implications for planning toward zero-energy urban development in hot and dry climates.
Finding- The baseline simulation resulted in an annual energy-consumption intensity of 103.61 kWh/m²/year. After the modeled improvement measures were applied, this value decreased to 56.62 kWh/m²/year, corresponding to a 45.3% reduction. The results indicate that improving building energy performance can provide a measurable evidence base for planning interventions in hot and dry climates. However, the reduction should not be interpreted as city-wide zero-energy achievement because the analysis is limited to a single building. The study therefore frames building-scale simulation as an initial step that can support subsequent multi-building and urban-scale energy planning.
Practical implications- The findings suggest that zero-energy urban development in hot and dry climates should be approached progressively, beginning with reductions in building energy demand and complemented by renewable-energy integration. For Semnan, climate-responsive building-envelope measures, improved glazing, and photovoltaic integration can be considered within a broader planning framework. Future research should test these strategies across multiple building types and urban scales and incorporate economic, spatial, and occupant-related variables.
Keywords: Zero-Energy Urban Development, Solar Energy, Urban Energy Planning, Hot and Dry Climate.

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1. Introduction

Climate change, increasing energy demand, and the environmental consequences of fossil fuel dependency have become major challenges for sustainable development. The building sector plays a significant role in global energy consumption and greenhouse gas emissions, making energy efficiency and renewable energy integration essential components of climate mitigation strategies (IEA, 2023; UNEP, 2023).Consequently, sustainable urban development approaches increasingly emphasize reducing energy demand, improving energy performance, and transitioning toward low-carbon energy systems. The concept of zero-energy development has emerged as an important framework for addressing these challenges. Initially developed at the building scale, zero-energy approaches aim to minimize energy demand through efficient design strategies and compensate remaining energy requirements through renewable energy generation (Maszal et al., 2011). However, recent perspectives suggest that achieving zero-energy objectives requires moving beyond individual buildings toward integrated urban systems in which buildings, infrastructure, renewable resources, and planning decisions interact (Reinhar & Cerezo Davila, 2016).

At the urban scale, energy consumption is influenced by multiple interconnected factors, including building characteristics, urban morphology, land-use patterns, and energy infrastructure. Therefore, zero-energy urban development requires coordinated strategies that integrate architectural solutions with urban planning frameworks. Such an integrated perspective is particularly important in regions where climatic conditions strongly influence energy demand.

Hot and dry climate regions face specific challenges related to energy consumption due to high solar radiation, elevated summer temperatures, and significant cooling requirements. In these regions, climate-responsive design strategies, including improved building envelopes, optimized glazing systems, shading strategies, and passive design principles, can contribute significantly to reducing energy demand (Givoni, 1998; Santamouris, 2016). At the same time, the high solar potential of these regions creates important opportunities for renewable energy integration, particularly photovoltaic systems. Iran, due to its geographical location and considerable solar resources, has significant potential for renewable energy development. However, many cities located in hot and dry regions continue to experience high energy consumption due to inefficient building design and limited integration of renewable energy technologies. Therefore, developing context-specific strategies that respond to local climatic conditions is necessary for improving urban energy sustainability.

Semnan city represents an appropriate case for investigating these challenges. Located in a hot and dry climatic region of Iran, Semnan experiences high solar availability while simultaneously facing increased cooling energy demands. Understanding how building-level interventions can reduce energy consumption and support renewable energy integration can provide valuable insights for sustainable planning strategies in this city and other similar climatic contexts.

Building energy simulation has become an important method for evaluating the effectiveness of energy-efficient strategies before their implementation. Simulation tools such as EnergyPlus and DesignBuilder enable researchers to analyze the relationship between building characteristics, climatic conditions, and energy performance (Crawly et al., 2001; Attia et al., 2012). These approaches provide quantitative evidence for comparing alternative scenarios and identifying effective strategies for reducing energy consumption.

However, previous studies indicate a methodological gap between building-scale simulation and urban-scale planning. While building energy models provide detailed information regarding technical performance, urban planning studies often require broader interpretations related to policies, regulations, and spatial development strategies (Reinhar & Cerezo Davila, 2016; Huang et al., 2017). Therefore, connecting simulation-based evidence with planning-oriented approaches remains an important research challenge.

In this context, the main research gap addressed by this study is the limited integration between building-scale energy simulation results and planning pathways toward zero-energy urban development, particularly in hot and dry climate regions. Although previous studies have investigated energy-efficient buildings and renewable energy systems, fewer studies have explored how simulation outcomes can inform urban planning strategies. Therefore, this study aims to identify planning pathways toward zero-energy urban development in hot and dry climates through a simulation-based assessment of a representative residential building in Semnan, Iran. The study uses DesignBuilder and EnergyPlus simulation tools to evaluate baseline energy performance and examine the potential contribution of energy-efficiency and solar-energy strategies.

The main research question is: How can building-scale energy simulation results contribute to identifying planning pathways toward zero-energy urban development in hot and dry climate cities such as Semnan? The objectives of this research are:To evaluate the baseline energy performance of a representative residential building in Semnan using building energy simulation.To assess the potential impact of energy-efficiency and solar-energy strategies on reducing energy consumption.To interpret simulation results as evidence for developing planning strategies toward zero-energy urban development.The innovation of this study lies in establishing a connection between simulation-based building assessment and urban planning perspectives. Rather than considering energy-efficient buildings as isolated technical solutions, this research demonstrates how building-scale evidence can support broader planning decisions in climate-sensitive urban environments.

2. Research Theoretical Literature

2.1. Zero-Energy Urban Development

From Energy-Efficient Buildings to Sustainable Urban Systems. The concept of "zero-energy" has shifted from focusing solely on individual high-performance buildings to encompassing broader, integrated urban sustainability frameworks. While zero-energy buildings (ZEBs) aim to balance annual energy consumption with local renewable production—primarily through demand reduction and on-site generation—this approach is now expanding to the neighborhood and city scales (Marique & Reiter, 2014).

Achieving zero-energy urban development requires moving beyond isolated technological solutions toward a holistic strategy that incorporates urban morphology, energy infrastructure, and planning policies. Because buildings are the primary drivers of urban energy demand, optimizing their performance remains a critical foundation (Koutra et al., 2018).

However, the transition to sustainable urban systems depends on effectively integrating building-level design, technological innovation, and systemic policy frameworks to optimize the interactions between buildings, renewable energy potential, and urban planning.

2.2. Building-Scale and Urban-Scale Approaches in Energy Planning

Energy studies in the built environment can generally be categorized into two interconnected scales: building-scale and urban-scale approaches. Building-scale approaches primarily focus on the physical characteristics and operational performance of individual buildings. These studies examine factors such as building orientation, envelope characteristics, glazing systems, insulation, thermal performance, energy systems, and renewable energy integration. Building Energy Modeling (BEM) and simulation tools such as EnergyPlus and DesignBuilder have become important methods for evaluating the influence of design strategies on energy consumption. At this scale, simulation-based studies allow researchers and designers to compare alternative scenarios before implementation. By modifying building characteristics and evaluating energy outcomes, simulation approaches provide evidence for selecting effective energy reduction strategies. Recent research demonstrates that building energy simulation can support decision-making by identifying optimal combinations of energy efficiency measures and renewable energy technologies (Reinhar & Cerezo Davila, 2016).

However, achieving urban energy goals requires considering interactions among multiple buildings and urban components. Urban-scale approaches examine larger systems, including building stocks, urban morphology, land-use patterns, energy infrastructure, and renewable energy distribution. Urban Building Energy Modeling (UBEM) has emerged as an approach for extending building energy simulation toward neighborhoods and cities. Unlike individual building models, UBEM evaluates energy performance across groups of buildings and provides information useful for urban planners and policymakers (Ferrando et al., 2020).

Despite the importance of urban-scale approaches, detailed urban energy modeling requires extensive data and computational resources. Therefore, building-scale simulation studies remain valuable as an initial step for identifying effective strategies and generating evidence that can inform broader planning decisions (Li et al., 2017).

Accordingly, this research adopts a building-scale simulation approach while interpreting its findings from an urban planning perspective. The study considers the simulated building as an experimental unit for identifying energy reduction strategies that can contribute to planning pathways toward zero-energy urban development.

2.3. Simulation-Based and Planning-Based Approaches

Energy planning research has increasingly incorporated simulation methods as tools for evaluating the consequences of design and policy decisions. Simulation-based approaches enable researchers to analyze the relationship between climatic conditions, building characteristics, energy demand, and renewable energy potential. Building simulation tools provide quantitative assessments of energy performance by modeling physical characteristics and operational conditions. These tools are particularly useful in regions with specific climatic challenges because they allow the evaluation of climate-responsive strategies before their implementation. In hot and dry climates, where cooling demand represents a major component of energy consumption, simulation-based assessment can help identify appropriate design solutions (Pan et al., 2023; Bian et al., 2025).

On the other hand, planning-based approaches focus on translating technical findings into strategies, regulations, and decision-making frameworks. Urban planners require evidence-based information to develop policies related to building standards, renewable energy adoption, urban form, and sustainable development. Recent research emphasizes the importance of linking simulation outputs with planning processes. Simulation results alone cannot achieve urban sustainability objectives unless they are translated into actionable planning strategies. Therefore, the integration of simulation-based assessment and planning-based interpretation represents an important pathway for achieving zero-energy development goals (Stermieri et al., 2020; Ang et al., 2020).

Based on this perspective, the present study establishes a connection between building energy simulation and urban planning by using simulation results as evidence for identifying planning implications in Semnan city.

2.4. Energy-Efficient Strategies in Hot and Dry Climates

Climatic conditions significantly influence building energy performance. Hot and dry regions are characterized by high solar radiation, significant temperature differences between day and night, low humidity, and high cooling requirements during warm seasons. Therefore, building design strategies in these regions should consider local climatic characteristics to minimize energy demand (Elnagar & Köhler, 2020; Tungnung, 2025).

Passive design strategies, including appropriate building orientation, thermal insulation, optimized glazing systems, shading devices, and climate-responsive envelope design, can reduce heat gain and improve indoor thermal conditions. These strategies are particularly important because reducing energy demand is considered the first step toward achieving zero-energy performance (Sartori et al., 2012; Torcellini et al., 2006).

In addition to passive strategies, renewable energy technologies, especially photovoltaic systems, provide opportunities for compensating remaining energy demand. The combination of demand reduction strategies and renewable energy generation represents a fundamental principle of zero-energy development (Tungnung, 2025).

For cities located in hot and dry climates, such as Semnan, integrating climate-responsive design with solar energy utilization can provide a practical pathway toward reducing dependence on conventional energy sources.

2.5. Solar Energy Potential and Zero-Energy Development

Solar energy is one of the most promising renewable resources for hot and dry regions due to high solar radiation availability. The integration of photovoltaic systems into buildings allows renewable energy production at the point of consumption and can contribute to reducing dependence on fossil fuels (Biyik et al., 2017; Belloni et al., 2024).

However, the effectiveness of solar energy integration depends on several factors, including building characteristics, available roof area, orientation, energy demand patterns, and climatic conditions. Therefore, solar technologies should not be considered independently but as part of an integrated energy strategy combining energy efficiency and renewable generation (Biyik et al., 2017; Belloni et al., 2024; Taşer et al., 2023).

In zero-energy development approaches, renewable energy generation is usually considered after reducing unnecessary energy demand. Consequently, improving building performance and integrating solar systems should be addressed simultaneously. This approach is particularly relevant for cities in hot and dry climates where solar availability is high but energy demand for cooling remains considerable (Abdul-Zahra & Al Jubori, 2021; Mirlohi et al., 2020).

2.6. Conceptual Framework of the Study

Based on the reviewed theoretical concepts, this study proposes a conceptual framework linking climatic conditions, building energy strategies, simulation analysis, and urban planning implications.

The framework consists of four main components:

1. Climatic Context: Hot and dry climate characteristics of Semnan, including high solar radiation and cooling demand.
2. Building Energy Strategies: Climate-responsive design measures and renewable energy integration, including improved glazing, energy-efficient building characteristics, and solar energy utilization.
3. Simulation-Based Evaluation: Assessment of energy performance using DesignBuilder and EnergyPlus simulation tools.
4. Planning Implications: Translation of simulation results into planning pathways and policy recommendations toward zero-energy urban development.

This framework assumes that building-scale simulation results can provide evidence for developing broader planning strategies. Although a single-building simulation cannot represent the entire urban energy system, it can identify effective strategies and provide a foundation for future multi-scale energy planning studies

2.7. Research background

Building-Scale Approaches in Zero-Energy Development- Previous research has largely focused on the building scale, investigating how design, passive strategies, and renewable technologies impact energy performance. Studies emphasize that optimizing the building envelope (insulation, glazing, and shading) is a crucial first step to reducing energy demand before integrating renewable sources.

Recent advancements, such as those highlighted by Kaitouni et al. (2025), show a significant evolution: modern buildings are no longer just designed for efficiency and comfort, but also to minimize life-cycle carbon emissions and interact with the urban environment. Driven by stricter regulations and digital tools, buildings are transitioning from passive consumers to "active prosumers" within smart grids. This enables them to achieve net-zero or even net-positive energy status, contributing to the broader concept of zero-energy communities.

-Zhao et al., (2025) in research titled: "Global warming likely compromises the annual performance of zero-energy buildings while the urban heat island effect exacerbates the impact" showed that total energy demand for space heating and cooling is predicted to increase by 24% and 38% under the RCP4.5 and RCP8.5 scenarios from 2021 to 2100, driven by global warming and the UHI effect. For extreme climates under the RCP4.5 scenarios, peak cooling and heating demands are expected to be 33% and 66% higher than the 80-year average, while rising to 39% and 71% under the RCP8.5 scenarios, respectively. Furthermore, current climate-based designs are unlikely to enable renewable energy generation to meet zero-energy requirements by 2100. This framework is therefore essential for enhancing the accuracy and reliability of energy system design for ZEBs.

-Li & Feng (2025) in an article:" Pathways to urban net zero energy buildings in Canada: A comprehensive GIS-based framework using open data" indicate that electrification and solar energy adoption in commercial districts, along with targeted retrofitting in residential zones, can significantly reduce energy use. This study provides a physics-based framework and robust methodology for Canadian cities to achieve net-zero energy goals, which offers valuable insights for policymakers, urban planners, and energy engineers to support decision-making and urban sustainability.

- Gondal (2024) in an article titled: “Low-speed wind energy devices to facilitate nearly zero energy buildings in urban Pakistan” showed that conventional wind turbines, effective in harnessing wind energy, face limitations in urban areas due to the requisite wind speeds. Micro wind turbines, notably vertical axis wind turbines (VAWT), present a promising solution for achieving net-zero energy buildings in urban settings. VAWTs exhibit advantages such as higher efficiency and lower cut-in speeds. Despite their promise, challenges such as reliability, cost and environmental impact persist.

-Taher Ahmadi et al., (2023) in an article titled: “Multi-objective optimization of energy demand and net zero energy building design based on climatic conditions (Case study: Tehran)” showed that climatic conditions and the appropriate selection of architectural parameters are very important and vital in reducing building energy consumption. Based on the results, the use of energy optimization solutions in Tehran leads to a 25.3% reduction in energy consumption. In addition, there is a significant potential for the use of photovoltaic systems in Tehran to provide energy for homes.

-Rezaeinasab et al., (2023) in an article titled: “Investigating the potential of designing net-zero energy buildings using photovoltaic installation with considering urban development plans requirements” showed that in a residential 3-story building the optimized configuration of the building envelope and systems can reduce electricity consumption by 20%. The rooftop PV account for 87.2% and PV installation on the southern façade contributed to 12.8% of total electricity generation. PV installation on the south façade and roof covers 88.2% of the building's electricity demand.

Urban-Scale Approaches in Zero-Energy Development- Urban-scale studies approach energy sustainability from a broader perspective by considering relationships among buildings, urban form, infrastructure, and energy systems. Unlike building-scale studies that focus primarily on individual performance, urban-scale approaches examine how multiple components of the urban system interact to influence energy consumption and renewable energy potential.

Previous research has investigated the influence of urban morphology, building density, land-use patterns, and spatial organization on urban energy performance. These studies indicate that planning decisions, including building arrangement, orientation, and urban structure, can affect solar access, energy demand, and opportunities for renewable energy integration (Zheng & Niu, 2021).

Simulation-Based Studies:

Evaluating Energy Performance Through Modeling- Simulation-based approaches have become one of the most widely used methods for assessing energy performance in buildings and urban environments. These approaches enable researchers to analyze the effects of alternative design strategies under controlled conditions and provide quantitative estimates of energy consumption (Ferrari & Zagarella, 2018).

Energy simulation tools such as EnergyPlus, DesignBuilder, TRNSYS, and similar platforms have been used extensively to evaluate the impacts of building envelope modifications, renewable energy integration, and climate-responsive design strategies. The main advantage of simulation-based methods is their ability to compare different scenarios without requiring physical implementation (Li et al., 2017; Reinhart & Cerezo Davila, 2016).

In recent years, simulation approaches have expanded from individual buildings toward urban energy modeling. Urban Building Energy Modeling (UBEM) has provided opportunities to analyze energy performance at neighborhood and city scales. However, the complexity of urban-scale modeling means that many studies continue to rely on representative building simulations as an initial step for understanding energy reduction opportunities (Reinhart & Cerezo Davila, 2016). The literature indicates that simulation results are most valuable when they are connected to decision-making processes. Without interpretation within a planning framework, simulation outputs remain technical assessments rather than practical strategies for sustainable urban development (Hwang & Lim, 2026).

Planning-Based Studies: Translating Energy Evidence into Urban Strategies- Planning-based studies focus on how energy objectives can be incorporated into urban development policies and spatial decision-making. These studies examine issues such as energy-efficient urban design, renewable energy planning, sustainability regulations, and governance mechanisms (Torabi Moghadam & Lombardi, 2019; OECD, 2022).

Research in this field highlights that achieving zero-energy urban development requires coordination between technical solutions and planning frameworks. Building standards, incentive programs, renewable energy policies, and urban regulations influence the adoption of energy-efficient strategies (Amaral et al., 2018; Horak et al., 2025).

However, many planning-oriented studies provide conceptual frameworks without detailed quantitative assessment of energy performance. This creates a gap between theoretical planning recommendations and measurable energy outcomes. Therefore, integrating simulation-based evidence with planning-based approaches can provide a more comprehensive pathway. Simulation can identify effective energy reduction strategies, while planning frameworks can determine how these strategies can be implemented at broader scales (Torabi Moghadam & Lombardi, 2019; Horak et al., 2025).

Research Gap- Based on the reviewed studies, previous research can be categorized into two main groups:

First, building-scale simulation studies have provided detailed assessments of energy efficiency strategies and renewable energy technologies. However, many of these studies remain limited to individual buildings and do not sufficiently address their implications for urban planning. Second, urban-scale planning studies have explored pathways toward sustainable and zero-energy urban development. However, many of these studies lack detailed simulation-based evidence regarding the effectiveness of specific building-level interventions. Therefore, a methodological gap exists between building energy simulation and urban planning. Particularly in hot and dry climate regions, there is a need for approaches that use building-scale simulation results as evidence for developing planning pathways toward zero-energy urban development. This study attempts to address this gap by connecting a simulation-based assessment of a representative residential building in Semnan with broader planning implications. The research does not consider a single building simulation as a complete representation of urban energy performance; rather, it uses the results as an evidence-based foundation for identifying strategies that can support future zero-energy urban development.

3. Research Methodology

3.1 Geographical Scope of the Research

This study is applied research based on a quantitative and simulation-based approach. The research aims to evaluate the potential of energy-efficiency and solar-energy strategies in reducing building energy consumption and to interpret their implications for zero-energy urban development in hot and dry climates (Figure 1).

Unlike survey-based studies that examine social perceptions or behavioral patterns, this research focuses on the physical performance of buildings through energy simulation. Therefore, the methodological framework is based on modeling, scenario development, simulation, and comparative analysis of energy performance.

The research process consists of four main stages:

Identification of climatic characteristics and energy challenges in Semnan city as a representative hot and dry climate region (Figure 2).

Development of a baseline energy model for a representative residential building.

Simulation of energy performance after applying energy-efficiency and solar-energy strategies.

Interpretation of simulation results to identify planning pathways toward zero-energy urban development.

The overall methodological framework establishes a connection between building-scale energy assessment and urban planning implications.

The case study of this research is Semnan city, located in the central part of Iran. The city is characterized by a hot and dry climate, with high solar radiation availability and significant cooling requirements during warm seasons (Figure 3).

The climatic conditions of Semnan create both challenges and opportunities for sustainable energy development. On one hand, high temperatures during summer increase cooling energy demand. On the other hand, considerable solar potential provides opportunities for renewable energy generation, particularly through photovoltaic technologies. Due to these climatic characteristics, Semnan represents an appropriate case for investigating how climate-responsive building strategies and solar energy utilization can contribute to reducing energy consumption and supporting pathways toward zero-energy urban development (Figure 4).

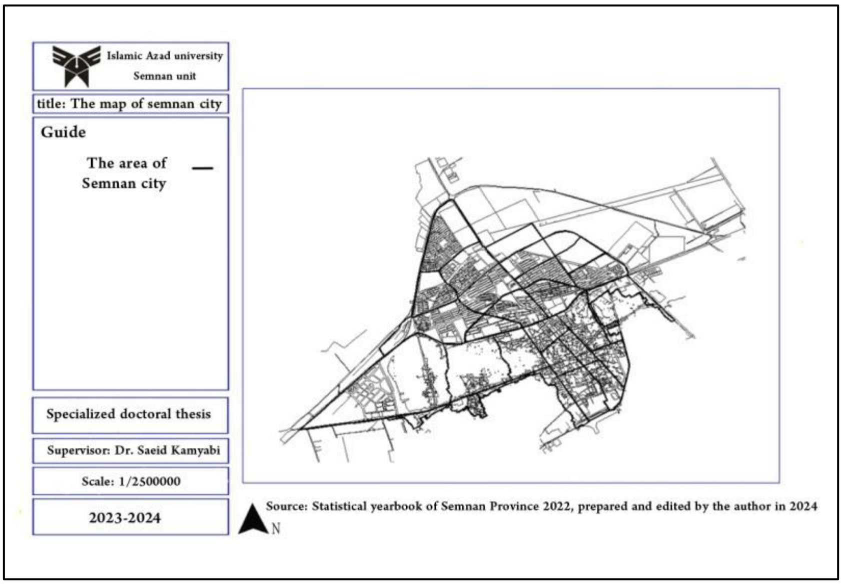

Figure 1. Map of Semnan city

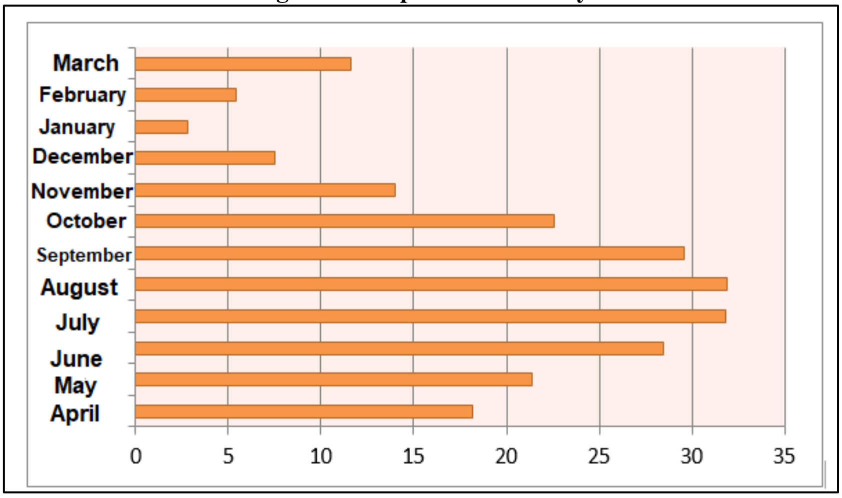

Figure 2. Average monthly temperature of Semnan city in degrees Celsius, based on the 2021 Statistical Yearbook
(Source: Ehteshamfar et al., 2024: 4)

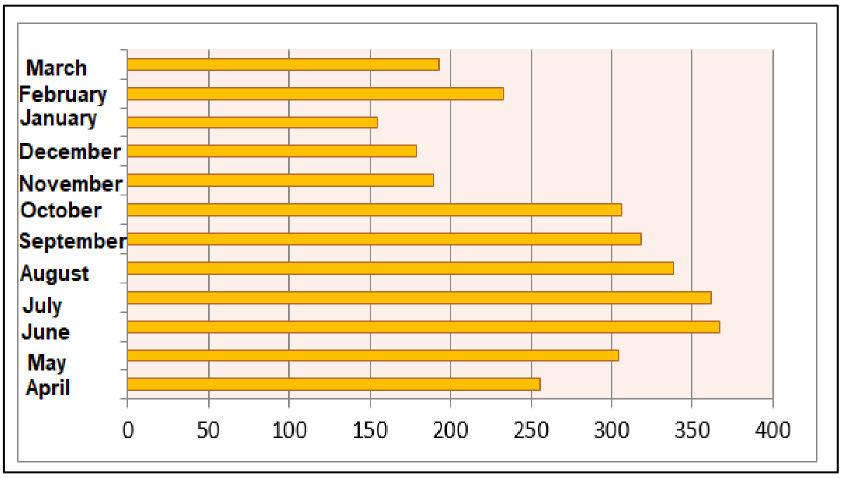

Figure 3. Sunshine hours in Semnan city, source: Statistical Yearbook 2021
(Source: Ehteshamfar et al., 2024: 4)

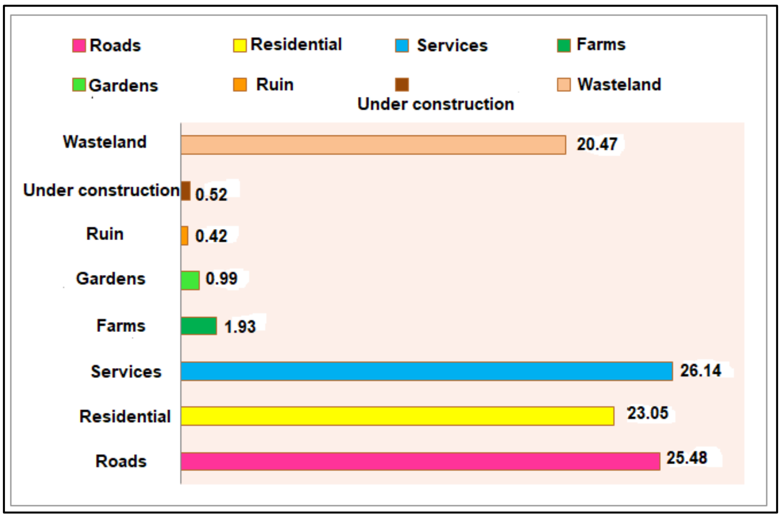

Figure 4. Percentage of land use in Semnan city, source: Statistical Yearbook 2021
(Source: Ehteshamfar et al., 2024: 4).

3.2. Methodology

To evaluate energy performance, a representative residential building located in Semnan was selected as the simulation case. The selected building represents a typical residential unit in the study area and has a total floor area of approximately 210 m².The building is a single-story residential building consisting of three bedrooms, a living room, kitchen, and bathroom spaces. The physical characteristics of the building, including its geometry and functional layout, were used to develop the simulation model. The building model was developed in DesignBuilder software, which uses the EnergyPlus simulation engine for dynamic energy performance analysis. The model was established to evaluate annual energy consumption under the climatic conditions of Semnan. The selected building was considered suitable for this study because its characteristics reflect common residential patterns in Semnan, including a single-story layout, typical residential functions, and a floor area consistent with local housing conditions. Therefore, it provides an appropriate case for evaluating the potential impact of energy-efficiency and solar-energy strategies in a hot and dry climatic context (Figure 5 and Table 1).

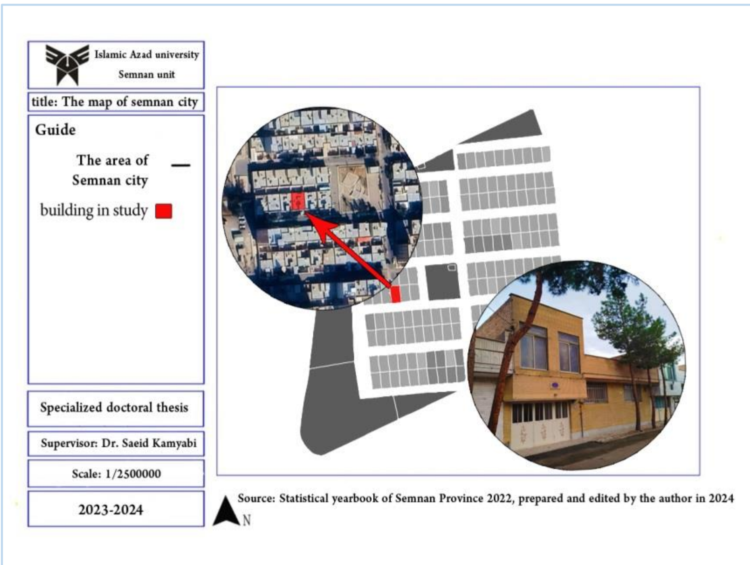

Figure 5. Building in study

Table 1. Specifications of the Case Study Building

Geographical Location	**Landuse**	**Building Orientation**	**Number of Floors**	**Roof Type**	**Floor Area**	**Façade Material**	**Window Area**	**Occupancy**	**Occupancy Hours**
Janbazan TownSemnan, Iran.	Residential	North-South	1	Flat	210 m 2	Steel Frame Brick	5m2 North 7m2 South	4	06:00 AM to 11:00 PM
Electrical Appliances	Lighting Type	Cooling System	Heating System	Natural Ventilation	Mechanical Ventilation	Opening Direction	Glazing Type	External Shading	Internal Shading
TV, Computer, Refrigerator, Washing Machine	22 × 100W Lamps	Water Cooler	Gas Heater	Windows	Water Cooler	South-facing	Single-glazed	Balcony	Venetian Blinds

3.3. Simulation Process

The simulation process was conducted using DesignBuilder and EnergyPlus. EnergyPlus is a widely used building energy simulation engine capable of evaluating heating, cooling, lighting, and overall energy performance based on building characteristics and climatic conditions. The simulation process included two main scenarios. Climatic data for Semnan city were extracted in EPW format using Climate Consultant software, based on the ASHRAE Standard 55-2004, and subsequently integrated into DesignBuilder for further analysis. (Figure 6)

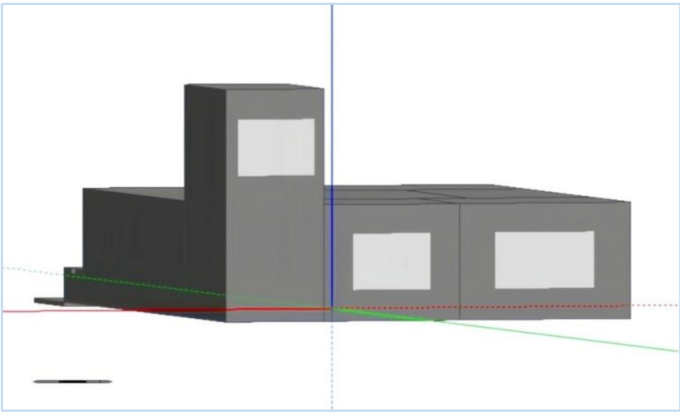

Figure 6. Simulation of the studied building in Design Builder software and its output

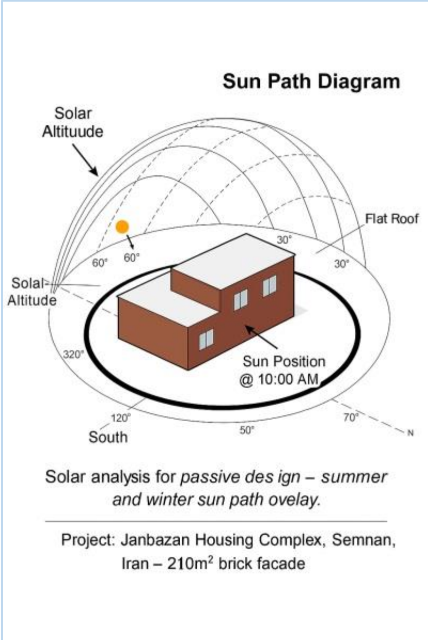

Figure 7. Simulation of the Solar path within the case study building

Scenario 1: Baseline Condition

In the baseline scenario, the selected residential building was simulated under its existing design conditions. This scenario represents the initial energy performance of the building before applying improvement strategies.

The purpose of this stage was to determine the annual energy consumption level and identify the potential for energy reduction.

Scenario 2: Improved Energy Performance Scenario

To minimize overall energy consumption, a multi-faceted approach involving passive design, HVAC optimization, and electrical load reduction was implemented. On the architectural level, energy efficiency was enhanced through optimal building orientation, strategic floor planning based on winter solar radiation, and the maximization of the Window-to-Wall Ratio (WWR) for daylighting, while ensuring thermal comfort via high-thermal-mass walls with integrated insulation. The building envelope was further optimized using double-glazed windows and climate-responsive shading devices. Regarding mechanical and thermal management, energy demand was mitigated by employing high-efficiency HVAC systems, utilizing heat recovery ventilation, and implementing nocturnal ventilation strategies to exploit nighttime cooling. Additionally, thermal loads were managed through precise thermostat setpoint adjustments and the use of external moist spaces for pre-cooling. Finally, electrical energy use was curtailed by installing low-power appliances, incorporating occupancy sensors, and integrating daylight harvesting controls to reduce reliance on artificial lighting (Figure 7).

3.4. Energy Performance Evaluation Criteria

The main evaluation indicator in this research was annual energy consumption intensity, expressed as kilowatt-hours per square meter per year (kWh/m²/year).

This indicator allows comparison between different building conditions and provides a standardized measure for evaluating energy performance.

The effectiveness of the proposed strategies was evaluated based on the reduction percentage between baseline and improved scenarios using the following equation:

The obtained results were subsequently analyzed from an urban planning perspective to identify how building-level energy improvements can contribute to broader zero-energy development strategies.

3.5. Analytical Framework of the Research

Based on the theoretical framework, this research proposes an analytical pathway linking climate characteristics, building strategies, simulation results, and planning implications.

The analytical framework consists of four interconnected components:

- Climate Context.

- Hot and dry climatic conditions of Semnan.
- Energy-Efficient Building Strategies.
- Climate-responsive design and solar energy integration.
- Simulation-Based Assessment.
- Design Builder/ Energy Plus evaluation of energy performance.
- Planning Implications.
- Identification of strategies supporting zero-energy urban development.

This framework highlights that building-scale simulation results can serve as evidence for developing urban planning strategies. However, the study recognizes that a single-building simulation cannot fully represent the energy performance of an entire city. Therefore, the findings are interpreted as a basis for identifying planning pathways rather than a direct estimation of city-wide zero-energy achievement.

3.6. Research Limitations Related to Methodology

The simulation-based approach provides detailed information about the energy performance of the selected building; however, several limitations should be acknowledged. First, the study focuses on a representative residential building and does not include the entire building stock of Semnan. Second, the simulation does not incorporate economic analysis, occupant behavior variations, or urban-scale energy modeling. Third, the transfer of building-level results to urban planning requires further investigation through multi-building and neighborhood-scale simulations. Despite these limitations, the methodology provides an evidence-based approach for identifying effective energy strategies and establishing a connection between building simulation and urban planning decisions.

4. Research Findings

Baseline Energy Performance of the Residential Building- The first stage of the simulation process evaluated the baseline energy performance of the selected residential building under the climatic conditions of Semnan.

The results of the baseline simulation showed that the annual energy consumption of the building was 103.61 kWh/m²/year. This value represents the energy demand of the building before applying energy-efficiency and renewable energy strategies. The baseline results indicate that residential buildings in hot and dry climates may experience considerable energy demand due to climatic conditions, particularly high cooling requirements during warm seasons. The obtained energy consumption level highlights the importance of applying climate-responsive design strategies and renewable energy solutions to reduce dependence on conventional energy sources.

From a planning perspective, identifying the baseline energy performance of representative buildings provides an initial evidence base for understanding energy challenges within the urban environment. Since buildings constitute one of the main components of urban energy consumption, improving their performance can contribute to broader strategies for sustainable and zero-energy urban development.

Energy Performance After Applying Improvement Strategies- In the second stage of the simulation, energy-efficiency and solar-energy strategies were incorporated into the building model to evaluate their potential contribution to reducing energy consumption.

The applied strategies included improvement of glazing performance through double-glazing systems, integration of solar energy through photovoltaic panels, and other energy reduction measures considered compatible with the climatic characteristics of Semnan.

The simulation results demonstrated a significant improvement in the energy performance of the building after applying the proposed strategies. The annual energy consumption decreased from 103.61 kWh/m²/year in the baseline scenario to 56.62 kWh/m²/year in the improved scenario.

This reduction indicates that climate-responsive building strategies combined with renewable energy integration can substantially decrease energy demand in hot and dry regions.

Comparative Analysis of Energy Performance- The comparison between the baseline and improved scenarios demonstrates the effectiveness of the proposed strategies.

Interpretation of Results for Zero-Energy Urban Development- Although the simulation was conducted at the building scale, the results provide important implications for urban energy planning.

The findings indicate that improving the energy performance of individual buildings can represent an important component of broader zero-energy urban development pathways. In cities with hot and dry climates, such as Semnan, building design strategies that respond to local climatic conditions can reduce energy demand and increase the feasibility of renewable energy integration. The results also demonstrate the importance of considering buildings as active components of urban energy systems. Instead of viewing energy consumption only as an operational issue, urban planning approaches can incorporate building performance criteria into development policies and regulations.

Therefore, the simulation outcomes of this study can be interpreted as evidence supporting several planning directions:

- ✓ promoting energy-efficient building standards;
- ✓ encouraging climate-responsive architectural design;
- ✓ increasing integration of solar energy technologies;
- ✓ developing policies that support low-energy and zero-energy buildings.

However, these findings should not be interpreted as indicating that the entire city of Semnan can achieve zero-energy status based only on a single-building simulation. Rather, they provide a methodological pathway for connecting building-level evidence with future urban-scale energy planning.

Summary of Findings- The main findings of the simulation analysis can be summarized as follows:

The baseline simulation indicated that the selected residential building consumed 103.61 kWh/m²/year under Semnan's hot and dry climatic conditions.

Applying energy-efficiency and solar-energy strategies reduced annual energy consumption to 56.62 kWh/m²/year.

The improved scenario achieved approximately 45.3% reduction in energy consumption intensity.

The results confirm the potential of integrating climate-responsive building strategies and renewable energy technologies as part of pathways toward zero-energy urban development.

The findings provide a building-scale evidence base that can support future urban planning strategies in hot and dry climate regions.

In the next step, the impact of various factors on the building's energy consumption is examined to minimize the building's energy consumption. Measures such as double-glazed windows, the use of solar panels, etc (Table 2).

Table 2. Energy calculation of the selected building after applying the solutions (Source: Research findings)

Energy	MJ	Cubic meter	Unit of consumption	Number of days
Gas	38234	37.68	10	365
Electricity	14762		91	365
		210	m^2	=A
MJ/m^2	203.83			=E actual
$kwh/year/m^2$	56.62			Equivalent

5. Discussion and Conclusion

The transition toward zero-energy urban development requires integrated approaches that connect building performance assessment, renewable energy utilization, and urban planning strategies. This study aimed to identify planning pathways toward zero-energy urban development in hot and dry climates through a simulation-based assessment of a representative residential building in Semnan, Iran.

Using DesignBuilder and the EnergyPlus simulation engine, the energy performance of the selected residential building was evaluated under baseline and improved conditions. The baseline simulation indicated an annual energy consumption of 103.61 kWh/m²/year. After applying energy-efficiency and solar-energy strategies, including improved glazing performance and photovoltaic integration, annual energy consumption decreased to 56.62 kWh/m²/year. This represents approximately 45.3% reduction in energy consumption intensity.

The findings demonstrate that climate-responsive building strategies and renewable energy integration can significantly improve energy performance in hot and dry regions. The results support the theoretical assumption that achieving zero-energy development requires prioritizing energy demand reduction before increasing renewable energy generation.

The main contribution of this research is establishing a connection between building-scale simulation and urban planning perspectives. While previous studies have often focused either on technical optimization at the building scale or conceptual strategies at the urban scale, this study demonstrates how simulation-based evidence can support planning decisions and policy development.

From a planning perspective, the findings suggest that zero-energy urban development in cities such as Semnan should be approached as a gradual and multi-scale process. Improving building energy performance, strengthening climate-responsive building regulations, encouraging solar energy integration, and developing supportive energy policies are essential steps toward sustainable urban development.

However, several limitations should be acknowledged. First, the research was based on a single representative residential building, and therefore the results cannot directly represent the energy performance of the entire city. Second, the study focused primarily on physical energy performance and did not consider economic aspects, occupant behavior, or social factors influencing energy consumption. Third, the simulation framework was conducted at the building scale and did not include neighborhood or city-scale energy modeling.

Future studies can extend this research by applying urban building energy modeling approaches to multiple building types and urban areas. Further research can also incorporate economic evaluation, life-cycle assessment, occupant behavior analysis, and spatial planning factors to develop more comprehensive zero-energy urban development frameworks.

Overall, this study demonstrates that building energy simulation can provide valuable evidence for developing sustainable planning pathways in hot and dry climates. Although achieving zero-energy status at the urban scale requires broader investigation, the integration of simulation-based assessment with planning strategies represents an important step toward climate-responsive and energy-efficient urban development.

Relationship Between Simulation Findings and Zero-Energy Urban Development- The findings of this study demonstrate that building-scale energy simulation can provide valuable evidence for developing pathways toward zero-energy urban development in hot and dry climates. The reduction of annual energy consumption from 103.61 kWh/m²/year in the baseline scenario to 56.62 kWh/m²/year after applying improvement strategies indicates the significant potential of climate-responsive design and renewable energy integration.

These findings support the theoretical perspective that achieving zero-energy development should begin with reducing energy demand before focusing on energy generation. Previous studies have emphasized that energy efficiency measures, including improved building envelopes, optimized glazing systems, and passive design strategies, represent fundamental steps toward reducing dependence on conventional energy sources. In this study, the improvement of building energy performance demonstrates that individual buildings can act as important components of broader urban energy systems. Since buildings represent a major share of urban energy consumption, improving their performance can contribute to the overall sustainability objectives of cities.

However, the results also confirm that zero-energy urban development cannot be achieved solely through isolated building interventions. Instead, building-scale improvements should be integrated with urban planning policies, renewable energy strategies, and regulatory frameworks.

From Building-Scale Simulation to Urban Planning Implications- One of the main contributions of this research is establishing a connection between building-scale simulation and urban planning perspectives.

Previous studies can generally be divided into two groups. The first group focuses on detailed building simulations and evaluates the effect of technical strategies on energy consumption. The second group examines urban energy planning but often lacks detailed quantitative evidence regarding the effectiveness of specific interventions.

This study attempts to bridge this gap by using simulation results from a representative residential building as evidence for identifying planning pathways. Although the simulation does not represent the entire energy system of Semnan, it demonstrates how building performance analysis can inform planning decisions.

The findings suggest that urban energy planning in hot and dry climates should not only consider large-scale renewable energy infrastructure but also address the energy performance of individual buildings. Therefore, policies related to building regulations, energy-efficient construction practices, and renewable energy integration should be considered as essential components of zero-energy urban development strategies.

The Role of Climate-Responsive Strategies in Hot and Dry Regions- The results highlight the importance of considering local climatic conditions in energy planning. Semnan, as a city located in a hot and dry climate region, experiences environmental conditions that increase cooling demand. Therefore, energy strategies that ignore climatic characteristics may have limited effectiveness.

The improvement achieved in the simulation scenario indicates that climate-responsive building design can play an important role in reducing energy demand. Strategies such as improving glazing performance and utilizing solar energy are particularly relevant in regions with high solar radiation availability.

These findings are consistent with the broader theoretical understanding that sustainable development strategies should be adapted to local environmental conditions rather than applying universal solutions. In hot and dry regions, the combination of passive design approaches and renewable energy technologies provides a practical pathway for improving energy performance.

Implications for Sustainable Urban Planning in Semnan- The findings of this research have several implications for urban planning in Semnan and similar cities.

First, energy performance criteria should receive greater attention in urban development policies. Traditional planning approaches often focus on land use, transportation, and physical growth, while building energy performance is considered mainly at the architectural scale. Integrating energy considerations into planning regulations can support more sustainable urban development.

Second, renewable energy utilization should be incorporated into urban development strategies. The high solar potential of hot and dry regions creates opportunities for distributed solar energy systems, particularly photovoltaic integration in residential buildings.

Third, planning policies should encourage the transition from conventional buildings toward energy-efficient and low-energy buildings through standards, incentives, and supportive regulations. The findings suggest that zero-energy urban development should be considered as a gradual process rather than an immediate outcome. This process begins with improving the energy performance of individual buildings and gradually expands toward neighborhood and city-scale energy systems.

Comparison with Previous Research- The findings of this study are consistent with previous research emphasizing the importance of simulation-based evaluation for improving building energy performance. Similar studies have demonstrated that energy simulation tools can effectively evaluate alternative design strategies and support evidence-based decision-making.

However, unlike studies that focus only on technical optimization at the building scale, this research emphasizes the planning implications of simulation outcomes. The main contribution is not only identifying energy reduction potential but also interpreting how such results can support urban planning strategies toward zero-energy development.

Therefore, the study contributes to the existing literature by providing a conceptual connection between simulation-based assessment and planning-based decision-making, particularly in hot and dry climatic contexts.

Scientific Contribution of the Study- The scientific contribution of this research can be summarized in three aspects:

- First, the study provides empirical evidence regarding the potential of energy-efficiency and solar-energy strategies in a hot and dry climate context.
- Second, it proposes an integrated perspective that connects building energy simulation with urban planning objectives.
- Third, it demonstrates that building-scale assessments can serve as an initial evidence base for developing broader zero-energy urban development pathways.

The research therefore contributes to the ongoing discussion on how technical energy assessments can be translated into planning strategies for sustainable urban development.

5.1. Planning and Policy Implications

Integrating Building Energy Performance into Urban Planning Policies- The findings of this study indicate that improving building energy performance can serve as an important pathway toward zero-energy urban development in hot and dry climates. Although energy consumption is often considered primarily a building-level issue, the results demonstrate that building characteristics and energy performance have direct implications for urban sustainability.

Therefore, urban planning policies in cities such as Semnan should incorporate building energy performance criteria into development frameworks. Traditional urban planning approaches that focus mainly on land use, density, and physical expansion should be complemented by energy-oriented considerations.

Integrating energy performance indicators into building regulations, development plans, and urban sustainability programs can support a gradual transition toward low-energy and zero-energy urban development.

Promoting Climate-Responsive Building Regulations- The simulation results demonstrate the importance of applying climate-responsive design strategies in reducing energy demand. Therefore, one of the main planning implications of this study is the necessity of strengthening energy-oriented building regulations in hot and dry regions.

Planning authorities can encourage:

- Improvement of building envelope performance;
- Application of efficient glazing systems;
- Appropriate consideration of building orientation;
- Integration of shading strategies;
- Improvement of thermal insulation standards.

These measures can reduce cooling demand and improve building performance without relying solely on energy supply solutions. For cities with climatic characteristics similar to Semnan, building regulations should be adapted to local environmental conditions rather than applying generalized standards.

Supporting Solar Energy Integration in Urban Development- The results of this study highlight the potential contribution of solar energy integration to reducing building energy demand. Considering the high solar availability in hot and dry regions, photovoltaic systems can become an important component of urban energy strategies.

From a planning perspective, solar energy integration can be supported through:

- Developing incentives for rooftop photovoltaic installation;
- Encouraging renewable energy integration in new residential developments;
- Considering solar accessibility in urban design decisions;
- Supporting local renewable energy programs.

However, solar energy should be considered as part of an integrated strategy. Renewable energy generation alone cannot achieve zero-energy goals without simultaneous reduction of energy demand through efficient building design.

Developing a Multi-Scale Energy Planning Approach- The findings of this research emphasize the importance of connecting different planning scales. The building-scale simulation provided evidence regarding effective energy strategies; however, achieving zero-energy urban development requires extending these strategies toward neighborhood and city scales.

Therefore, future urban energy planning in Semnan should consider a multi-scale approach:

- Building scale:

Improving individual building energy performance through efficient design and renewable energy integration.

- Neighborhood scale:

Evaluating energy interactions among groups of buildings and identifying opportunities for shared renewable energy systems.

- Urban scale:

Developing comprehensive energy planning frameworks, regulations, and sustainability policies.

This multi-scale perspective can help overcome the gap between technical building solutions and broader urban planning objectives.

Institutional and Economic Support for Energy Transition- The transition toward zero-energy urban development requires not only technical solutions but also institutional and economic support. Energy-efficient strategies often require initial investment, and therefore supportive mechanisms are necessary to encourage adoption.

Policy measures may include:

- Providing financial incentives for energy-efficient construction;
- Supporting renewable energy investments;
- Encouraging energy performance assessment during building approval processes;
- Increasing awareness among designers, developers, and residents.

Such measures can facilitate the adoption of energy-efficient practices and accelerate the transition toward sustainable urban development.

Planning Framework for Semnan and Similar Hot and Dry Cities- Based on the findings of this research, a planning pathway for hot and dry cities can be proposed:

- Step 1: Assessment of existing building energy performance;

- Step 2: Identification of climate-responsive improvement strategies;
- Step 3: Simulation-based evaluation of proposed interventions;
- Step 4: Integration of effective strategies into building regulations and urban policies;
- Step 5: Expansion from individual buildings toward neighborhood and urban energy planning.

This framework demonstrates that zero-energy urban development should be considered as a progressive planning process rather than a single technological intervention.

Implications for Rural and Regional Planning Contexts- Considering the focus of planning studies on regional sustainability, the findings also have implications beyond urban boundaries. Many small towns and rural settlements located in hot and dry regions share similar climatic challenges and energy consumption patterns. The integration of climate-responsive design and renewable energy strategies can contribute to improving energy resilience in these areas. Therefore, the proposed approach can provide a transferable framework for other settlements with similar environmental conditions.

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Author Contributions

The authors contributed equally to the development and preparation of this research.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the authorship or publication of this article.

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Original Article

مسیرهای برنامه‌ریزی برای گذار به توسعه شهری با انرژی صفر در اقلیم‌های گرم و خشک: مطالعه‌ای شبیه‌سازی‌محور در شهر سمنان، ایران

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چکیده مبسوط

۱. مقدمه

رشد شهرنشینی، افزایش تقاضای انرژی و پیامدهای زیست‌محیطی مصرف سوخت‌های فسیلی، ضرورت حرکت به سوی الگوهای توسعه شهری کم‌کربن و انرژی‌کارآمد را افزایش داده است. در این میان، بخش ساختمان یکی از مهم‌ترین مصرف‌کنندگان انرژی به شمار می‌رود و عملکرد انرژی آن تحت تأثیر عواملی همچون ویژگی‌های کالبدی، فرم و جهت‌گیری ساختمان، مصالح، اقلیم و الگوی بهره‌برداری قرار دارد. مفهوم توسعه شهری انرژی‌صفر نیز از تمرکز صرف بر ساختمان‌های منفرد فراتر رفته و به سمت رویکردهای یکپارچه در مقیاس محله و شهر حرکت کرده است. این موضوع در شهرهای واقع در اقلیم گرم و خشک اهمیت بیشتری دارد؛ زیرا تابش خورشیدی فراوان، دمای بالای تابستان و نیاز قابل‌توجه به سرمایش، هم‌زمان ظرفیت و چالش مهمی برای برنامه‌ریزی انرژی ایجاد می‌کند. با وجود ظرفیت مناسب انرژی خورشیدی در ایران، ناکارآمدی پوسته ساختمان و محدود بودن استفاده از انرژی‌های تجدیدپذیر، دستیابی به توسعه شهری انرژی‌صفر را با چالش مواجه کرده است. ازاین‌رو، پژوهش حاضر با هدف بررسی نقش شبیه‌سازی عملکرد انرژی ساختمان در شناسایی مسیرهای برنامه‌ریزی برای توسعه شهری انرژی‌صفر در اقلیم گرم و خشک، شهر سمنان را به‌عنوان مطالعه موردی انتخاب کرده است.

۲. مبانی نظری تحقیق

مبانی نظری پژوهش بر پیوند میان برنامه‌ریزی انرژی شهری، عملکرد انرژی ساختمان و توسعه انرژی‌صفر استوار است. مطالعات پیشین نشان می‌دهند که دستیابی به شهرهای انرژی‌کارآمد مستلزم توجه هم‌زمان به کاهش تقاضای انرژی، بهبود عملکرد ساختمان‌ها، استفاده از انرژی‌های تجدیدپذیر و سیاست‌گذاری فضایی است. مدل‌سازی انرژی ساختمان (BEM) و ابزارهایی مانند EnergyPlus و DesignBuilder امکان ارزیابی کمی عملکرد انرژی و مقایسه سناریوهای مختلف را فراهم می‌کنند. در مقیاس بزرگ‌تر، مدل‌سازی انرژی ساختمان‌های شهری (UBEM) می‌تواند این رویکرد را به سطح محله و شهر تعمیم دهد. در اقلیم گرم و خشک، راهبردهایی نظیر جهت‌گیری مناسب، عایق‌کاری حرارتی، بهینه‌سازی سطح و نوع پنجره‌ها، سایه‌اندازی، پوسته اقلیم‌پاسخ، تهویه طبیعی و استفاده از سامانه‌های خورشیدی اهمیت ویژه‌ای دارند. بر این اساس، چارچوب مفهومی پژوهش شامل چهار مؤلفه اصلی «زمینه اقلیمی»، «راهبردهای انرژی ساختمان»، «ارزیابی مبتنی بر شبیه‌سازی» و «پیامدهای برنامه‌ریزی» است. خلأ اصلی مطالعات پیشین نیز در فاصله میان نتایج کمی شبیه‌سازی ساختمان و تبدیل این نتایج به مسیرهای عملی برنامه‌ریزی شهری شناسایی شده است.

۳. روش تحقیق

پژوهش از نظر هدف، کاربردی و از نظر روش، کمی و مبتنی بر شبیه‌سازی است. فرآیند تحقیق در چهار مرحله انجام شد: شناسایی شرایط اقلیمی، ایجاد مدل پایه، تعریف سناریوی بهبودیافته و تفسیر نتایج در چارچوب برنامه‌ریزی شهری. شهر سمنان به دلیل قرارگیری در اقلیم گرم و خشک، تابش خورشیدی مناسب و نیاز قابل‌توجه به سرمایش به‌عنوان مطالعه موردی انتخاب شد. برای ارزیابی، یک ساختمان مسکونی یک‌طبقه نماینده با زیربنای تقریبی ۲۱۰ مترمربع در شهرک جانبازان سمنان مدل‌سازی شد. شبیه‌سازی دینامیکی با استفاده از نرم‌افزار DesignBuilder و موتور EnergyPlus انجام گرفت. در سناریوی پایه، مشخصات واقعی ساختمان شامل جهت‌گیری شمالی–جنوبی، پوسته، پنجره‌ها، سیستم‌های گرمایش و سرمایش، تجهیزات و الگوی حضور ساکنان لحاظ شد. در سناریوی بهبودیافته، مجموعه‌ای از راهبردهای اقلیم‌پاسخ و انرژی‌کارآمد، از جمله بهبود جهت‌گیری، افزایش جرم حرارتی و عایق‌کاری،

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پنجره‌های دوجداره، سایه‌اندازی خارجی، سیستم‌های کارآمد تهویه و سرمایش، تهویه شبانه، تنظیم دمای ترموستات، کاهش مصرف تجهیزات و روشنایی، استفاده از نور روز و انرژی خورشیدی مورد ارزیابی قرار گرفت. شاخص اصلی ارزیابی، شدت مصرف سالانه انرژی بر حسب کیلووات‌ساعت بر مترمربع در سال بود.

۴ .یافته‌های تحقیق

نتایج شبیه‌سازی نشان داد که شدت مصرف سالانه انرژی در سناریوی پایه ۶۱/۱۰۳ کیلووات‌ساعت بر مترمربع در سال است. اعمال مجموعه راهبردهای بهبودیافته، این مقدار را به ۶۲/۵۶ کیلووات‌ساعت بر مترمربع در سال کاهش داد که بیانگر ۳/۴۵ درصد کاهش مصرف انرژی نسبت به وضعیت پایه است. نتایج بر اهمیت ترکیب راهبردهای کاهش تقاضا با بهبود پوسته ساختمان، ارتقای شیشه‌ها، سایه‌اندازی و استفاده از انرژی خورشیدی تأکید دارد. از منظر برنامه‌ریزی، یافته‌ها نشان می‌دهند که تدوین استانداردهای انرژی‌کارآمد ساختمان، تقویت معماری اقلیم‌پاسخ، تسهیل ادغام سامانه‌های خورشیدی و حمایت از سیاست‌های مرتبط با ساختمان‌های کم‌مصرف و انرژی‌صفر می‌تواند در مسیر کاهش مصرف انرژی شهری مؤثر باشد. بااین‌حال، به دلیل محدود بودن مطالعه به یک ساختمان نماینده، نتایج شبیه‌سازی را نمی‌توان مستقیماً به کل شهر سمنان تعمیم داد یا بر مبنای آن ادعای تحقق انرژی‌صفر در مقیاس شهری مطرح کرد.

۵ .بحث و نتیجه‌گیری

یافته‌های پژوهش نشان می‌دهد که توسعه شهری انرژی‌صفر در اقلیم گرم و خشک، بیش از آنکه صرفاً به افزایش تولید انرژی تجدیدپذیر وابسته باشد، نیازمند کاهش تقاضای انرژی و ارتقای عملکرد ساختمان‌هاست. نتایج حاصل از شبیه‌سازی نشان داد که ترکیب راهبردهای اقلیم‌پاسخ و انرژی‌کارآمد می‌تواند کاهش قابل‌توجهی در مصرف انرژی ایجاد کند و مبنایی کمی برای تصمیم‌گیری و سیاست‌گذاری فراهم آورد. مهم‌ترین دستاورد پژوهش، ایجاد پیوند میان ارزیابی عملکرد انرژی در مقیاس ساختمان و الزامات برنامه‌ریزی شهری است. بر این اساس، مسیر پیشنهادی شامل پنج گام است: ارزیابی عملکرد موجود ساختمان‌ها، شناسایی راهبردهای اقلیمی مناسب، آزمون و مقایسه راهبردها از طریق شبیه‌سازی، تبدیل راهبردهای مؤثر به ضوابط و سیاست‌های اجرایی، و در نهایت تعمیم نتایج از مقیاس ساختمان به محله و شهر. بنابراین، تقویت مقررات انرژی ساختمان، ارتقای پوسته و شیشه، توجه به جهت‌گیری و سایه‌اندازی، حمایت از نصب سامانه‌های خورشیدی و ایجاد مشوق‌های مالی و اجرایی می‌تواند زمینه‌ساز حرکت تدریجی به سوی توسعه شهری انرژی‌صفر باشد. پژوهش حاضر در عین حال بر ضرورت مطالعات آتی در مقیاس چندساختمانی و شهری، با استفاده از مدل‌سازی UBEM و در نظر گرفتن ابعاد اقتصادی، چرخه عمر، رفتار بهره‌برداران و برنامه‌ریزی فضایی تأکید دارد.

کلیدواژه‌ها: توسعه شهری بدون انرژی، انرژی خورشیدی، برنامه‌ریزی انرژی شهری، اقلیم گرم و خشک.

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