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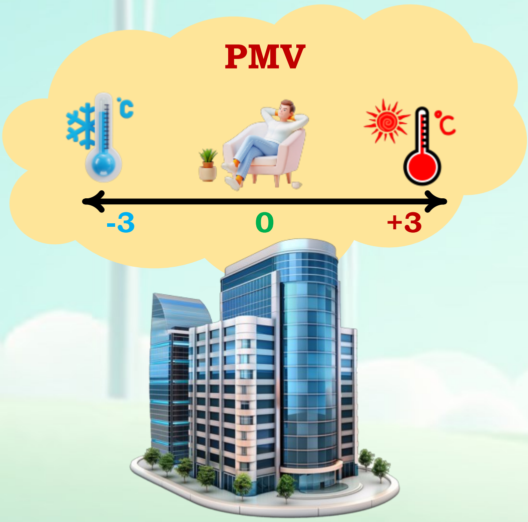
Highlights

- **The energy consumption for the cooling and heating across eight different building scenarios was compared.**
- **The three climate scenarios represented the cities of Yazd (hot), Arak (moderate), and Shahr-e Kord (cold) were modelled.**
- **buildings without common walls (single floors) could have 58.9% and 67.1% more load and energy consumption in heating and cooling, respectively.**
- **The difference between the energy consumption of the building with the highest and lowest number of shared walls was observed to be about 60% on average.**

Graphical Abstract



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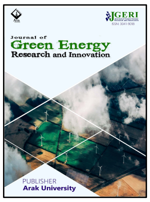

An Analysis of Heating and Cooling Energy Consumption in High-Rise Versus Low-Rise Buildings with Reference to The Predicted Mean Vote (pmv) Comfort Index: A Case Study

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ABSTRACT

The choice between residing in tall buildings and in few-story or detached dwellings has been the subject of considerable debate, with each approach attracting its own proponents and critics. This study investigates and compares the heating and cooling energy consumption of multi-story and low-elevation buildings, incorporating the Fanger comfort index as a measure of thermal comfort. Energy performance is evaluated on eight building configurations with varying numbers of floors, under three distinct climatic conditions, using the Predicted Mean Vote (PMV) index as the primary comfort criterion. The building scenarios range from single-story detached houses to 50-story high-rise structures. The climatic cases—representing hot (Yazd), moderate (Arak), and cold (Shahr-e Kord) environments—are simulated and analyzed using DesignBuilder software. The results section presents detailed analyses of heating and cooling loads, comfort index values, and electricity and gas demand for each building–climate combination, with monthly and annual performance trends. The findings reveal that the number of shared walls exerts a greater influence on energy consumption than the number of floors. Specifically, detached single-story buildings, which lack shared walls, exhibit up to 58.9% higher heating demand and 67.1% higher cooling demand compared to their counterparts with shared walls.

1. Introduction

In recent years, the debate between vertical residential developments (high-rise buildings) and horizontal, independent housing has intensified, with both approaches attracting strong proponents and critics. High-rise buildings are common in densely populated areas where horizontal expansion is limited, while detached, low-rise dwellings are preferred in regions where families seek greater privacy, exclusive ownership, and larger living spaces. Each of these residential forms has distinct implications for energy consumption, energy efficiency, occupant comfort, and environmental sustainability. Escalating global concerns over energy scarcity and supply instability have intensified the demand for energy-efficient residential solutions. With the growing emphasis on sustainable urban development and the evolution of architectural practices, the accurate modeling and optimization of buildings' energy performance have become increasingly vital. This issue is especially pronounced in the Middle East, where accelerated population growth and mounting energy consumption underscore the pressing need to reconcile resource preservation with the provision of thermal comfort for occupants. In recent decades, two dominant paradigms of residential development—vertical expansion through high-rise buildings and horizontal expansion through low-rise, detached dwellings—have been the focus of considerable scholarly and professional debate. Each approach is underpinned by distinct socio-economic, cultural, and environmental drivers, and both have their respective advocates and critics.

High-rise developments are increasingly adopted in densely populated urban centers, where limited land availability, rapid urbanization, and the need to optimize infrastructure necessitate vertical growth. By contrast, low-rise and independent housing typologies remain prevalent in areas where land is more accessible and where residents prioritize privacy, individual ownership, outdoor spaces, and a stronger connection with the surrounding environment.

The implications of these two development strategies extend well beyond architectural form and urban density. They have profound consequences for building energy consumption, operational efficiency, and occupant well-being, as well as for broader environmental sustainability. High-rise buildings, while often associated with economies of scale and shared infrastructure, may face challenges related to increased cooling and heating loads due to higher exposure of façades, complex HVAC requirements, and greater reliance on artificial ventilation and lighting. Conversely, low-rise dwellings typically benefit from simpler design and operation, greater adaptability to passive design strategies, and reduced dependence on mechanical systems, but they may contribute to urban sprawl, higher land consumption, and increased transportation-related energy use. Understanding the trade-offs between these residential typologies is therefore crucial for architects, urban planners, and policymakers seeking to balance energy efficiency, occupant comfort, and sustainable urban growth.

Worldwide, escalating concerns regarding energy deficits and imbalances between supply and demand have emerged as critical challenges, underscoring the urgent need for the adoption of energy-efficient residential strategies. Concurrently, the global transition toward sustainability-driven urban development, combined with rapid innovations in architectural design and building technologies, has heightened the importance of accurately modeling and optimizing the energy performance of residential buildings. These challenges are particularly pronounced in the Middle East, where rapid population growth, urbanization, and rising energy consumption converge to create a multifaceted problem: achieving an optimal balance between resource conservation, environmental sustainability, and the comfort and well-being of building occupants. In this context, the development of integrated design and simulation approaches is essential for supporting evidence-based decisions that enhance energy efficiency while maintaining high standards of thermal comfort and livability.

At the urban scale, Urban Building Energy Modeling (UBEM) has emerged as a valuable framework for analyzing and optimizing energy consumption [1]. Unlike top-down models that rely on aggregated time-series data, UBEM adopts a bottom-up methodology, enabling more detailed evaluations of technological performance at the building level, as noted by Reinhardt and Cerezo Davila [2]. Energy simulation platforms such as Design Builder, EnergyPlus, and TRNSYS further support this process by allowing scholars to investigate specific building typologies and their environmental implications [3,4]. According to Hong et al. [5], multi-story buildings are typically associated with greater cooling demands due to elevated solar exposure, whereas low-rise buildings often exhibit higher heating requirements because of their extensive envelope area. Moreover, building geometry plays a critical role in shaping energy efficiency. Kim et al. [6] demonstrated that variations in architectural form can substantially influence energy demand, while Chen et al. [7] underscored the importance of localized climatic variables—such as temperature, solar radiation, and humidity—in determining the design of region-specific HVAC strategies.

The optimization of Heating, Ventilation, and Air Conditioning (HVAC) systems plays a pivotal role in reducing energy consumption and enhancing overall building performance. Kimura et al. [8] demonstrated that tailoring HVAC configurations to specific climatic conditions can yield significant operational benefits. Their study indicated that gas-based heating systems outperform electric alternatives in cold climates, while evaporative cooling technologies achieve higher efficiency in hot, arid regions. These findings underscore the potential for substantial annual energy savings in residential buildings and highlight the critical importance of implementing climate-responsive HVAC design strategies.

Moreover, the effectiveness of HVAC optimization is closely linked to building typology. High-rise buildings, with their extensive façade exposure and complex internal layouts, often require sophisticated HVAC strategies to maintain uniform thermal comfort across multiple floors, whereas low-rise, detached dwellings can more readily exploit passive heating and cooling techniques alongside simpler HVAC configurations. Advanced energy modeling tools, such as DesignBuilder, EnergyPlus, and similar simulation platforms, provide the ability to assess the interaction between building design, local climate, and HVAC performance, enabling designers and engineers to identify the most efficient and comfortable system configurations for each context. Integrating such modeling approaches with climate-sensitive HVAC strategies is therefore essential for achieving both energy efficiency and optimal occupant comfort in diverse residential typologies.

Yu et al. [9] demonstrated that Variable Air Volume (VAV) systems outperform Constant Air Volume (CAV) systems in terms of energy efficiency, particularly in mixed-use urban buildings where fluctuating occupancy patterns and diverse functional requirements necessitate flexible climate control. VAV systems adjust the airflow rate based on real-time thermal demand, thereby reducing unnecessary energy consumption and enhancing occupant comfort compared to the fixed-flow operation of CAV systems. In addition to HVAC system optimization, material selection and façade design play a crucial role in improving building performance. The use of high-performance insulation materials, low-emissivity glazing, and adaptive façade technologies can significantly reduce heat transfer, optimize natural lighting, and minimize cooling and heating loads. Collectively, these design strategies highlight the importance of integrating mechanical system efficiency with passive architectural features to achieve substantial improvements in overall building energy performance. According to Gong et al. [10], the use of materials with high solar reflectance and low thermal emittance can effectively reduce cooling loads in warm climates by minimizing heat absorption. Building envelope characteristics, particularly the window-to-wall ratio (WWR) and glazing specifications, also have a pronounced impact on energy efficiency. Wang et al. [11] observed that larger WWRs are advantageous in colder climates, whereas smaller ratios are more suitable in warmer regions. Comfort considerations further extend to adaptive models; Page et al. [12] emphasized that incorporating occupant-specific comfort variations allows for greater flexibility in designing energy-efficient indoor environments.

Building-Integrated Photovoltaics (BIPVs) represent another significant strategy for enhancing building efficiency, especially in solar-abundant areas. Yalcin and Selcuk [13] demonstrated that integrating BIPVs with cooling strategies can substantially reduce dependence on conventional grid power. The rise of smart technologies, including Internet of Things (IoT)-enabled systems, has also transformed energy management practices. Wang et al. [14] demonstrated that the integration of real-time monitoring systems with big data analytics significantly enhances the calibration of building energy models, thereby reducing the discrepancies between simulated predictions and actual operational performance. This advancement not only increases the reliability of energy modeling but also provides a more accurate basis for decision-making in building design and energy management. Similarly, Dong et al. [15] reported that the deployment of smart technologies such as occupancy sensors and intelligent thermostats facilitates dynamic control of HVAC systems. By adapting heating, cooling, and ventilation schedules in response to real-time occupancy patterns, these technologies have been shown to reduce residential energy consumption by more than 25%. Such findings underscore the transformative role of digitalization and smart control strategies in bridging the performance gap, optimizing energy use, and advancing the development of resilient, energy-efficient buildings.

Policy frameworks play an equally important role in driving efficiency improvements. Yan et al. [16] highlighted the effectiveness of rigorous energy-efficient construction standards in promoting sustainable practices. Comparative analyses of high-rise and low-rise housing also inform urban planning strategies; Buffat et al. [17] demonstrated that GIS-based modelling facilitates optimized urban energy planning. Moreover, urban heat island phenomena significantly influence energy demand. Xu et al. [18] argued that integrating microclimatic conditions—such as localized temperature variations, wind patterns, solar radiation intensity, and humidity levels—into building energy simulation models substantially improves predictive accuracy. By accounting for these site-specific factors, simulation outcomes more closely align with real-world energy performance, thereby reducing the uncertainties commonly associated with generalized climate assumptions. Furthermore, the inclusion of microclimatic variables enables the development of more effective optimization strategies for building design and operation, particularly in urban contexts where factors like shading from surrounding structures, urban heat islands, and localized airflow can significantly influence thermal comfort and energy demand. This approach ultimately supports the design of context-sensitive, energy-efficient buildings that are better adapted to their immediate environmental conditions.

To address the increasing complexity of urban energy systems, new modelling frameworks have been developed. Remmen et al. [19] introduced TEASER, an open-source platform for urban energy modelling of building stocks, capable of integrating heterogeneous datasets for scalable assessments. Complementarily, Ferrando et al. [20] reviewed bottom-up, physics-based UBEM approaches, outlining emerging trends and identifying key opportunities for advancing energy-efficient building design.

Advancements in geospatial data integration have significantly improved the accuracy of urban heat demand modeling. Nouvel et al. [21] highlighted the critical role of data quality, showing that 3D city models with high-resolution geospatial datasets yield more precise energy demand predictions. Furthermore, Nouvel et al. [22] demonstrated that coupling GIS-based statistical and engineering approaches provides a robust framework for multi-scale policy support in urban energy planning, effectively linking neighborhood-level analyses with broader city-scale assessments. Recent studies have also employed advanced simulation tools, particularly Design Builder, to model energy performance across diverse building typologies and case studies [23-27].

Several studies have investigated the impact of building geometry on energy performance, highlighting that high-rise buildings with more shared walls tend to exhibit reduced heat loss and energy demand compared to low-rise or detached structures due to minimized exposed surfaces [28,29]. While the Fanger PMV model is widely used for assessing thermal comfort, it has been criticized for its limitations in residential and naturally ventilated settings, as it does not account for adaptive behaviors such as clothing adjustment or window operation [30]. Recent advancements propose adaptive comfort models that better reflect real occupant responses, particularly in diverse climate zones, often resulting in 15–20% energy savings compared to PMV-based systems [31,32]. Moreover, enhanced modeling approaches now incorporate vertical temperature gradients or artificial intelligence (AI)-based HVAC optimization to improve both comfort prediction and energy efficiency [33,34].

To address existing knowledge gaps in residential building performance, this study conducts a comprehensive evaluation of eight building scenarios in combination with three distinct HVAC system configurations, spanning a wide spectrum of building types—from single-unit villas to 50-story high-rise structures. The primary focus of the analysis is the application of the Predicted Mean Vote (PMV) comfort index, which serves as a quantitative measure of thermal comfort for building occupants. Simulations are carried out using DesignBuilder software, incorporating detailed modeling of building geometry, material properties, occupancy patterns, and HVAC operational strategies.

The study is performed across three representative Iranian cities—Yazd, Arak, and Shahr-e Kord—each representing unique climatic conditions, including hot-arid, moderate, and cold climates, respectively. By examining the interaction between building design, HVAC systems, and local climate, the research aims to identify key factors that influence energy consumption, thermal comfort, and overall building performance.

The insights gained from this study are intended to provide practical guidance for architects, engineers, urban planners, and policymakers in designing and implementing high-performance residential developments. In particular, the findings may inform decisions related to building typology, HVAC selection, and climate-responsive design strategies, ultimately supporting the development of energy-efficient, comfortable, and sustainable urban housing solutions. The anticipated findings are expected to contribute to the broader discourse on climate-responsive architecture and sustainable energy management within the context of urban development, offering both design-oriented and policy-relevant implications.

2. Different Building Scenarios

Due to spatial constraints—particularly in major economic, political, and social centers—high-rise construction has emerged as a prevalent solution in urban areas worldwide. Figure 1 illustrates several notable examples of high-rise buildings, highlighting the global trend toward vertical residential development. In contrast, recent years have seen an increasing preference for low-rise, independent housing, driven by residents' desire for greater autonomy, privacy, and comfort, as well as the rise of residential communities structured around such typologies. Figure 2 depicts the newly developed Amirkabir city near Arak, Iran, which predominantly comprises flat housing units.

In the present study, eight building scenarios with varying block configurations and floor counts, as detailed in Figure 3 and Table 1, are systematically modeled and compared to evaluate their energy demand. The analysis considers both heating and cooling requirements, incorporating factors such as building geometry, climatic conditions, and HVAC system performance, in order to provide a comprehensive understanding of how different residential typologies influence energy efficiency and thermal comfort.

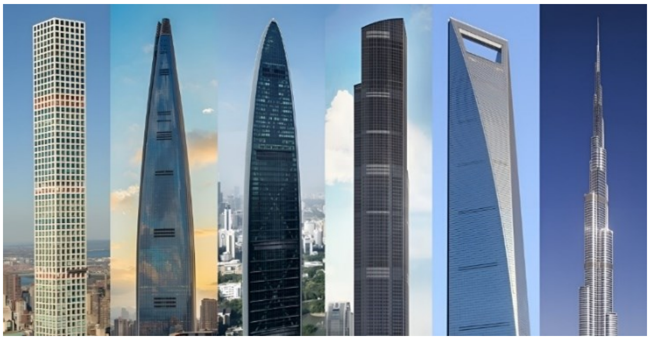

Figure 1. Notable high-rise buildings around the world, illustrating global trends in tall building construction.

Figure 2. Comparison of high-rise developments and low-rise housing in Amirkabir New Town near Arak, Iran, illustrating alternative urban residential typologies.

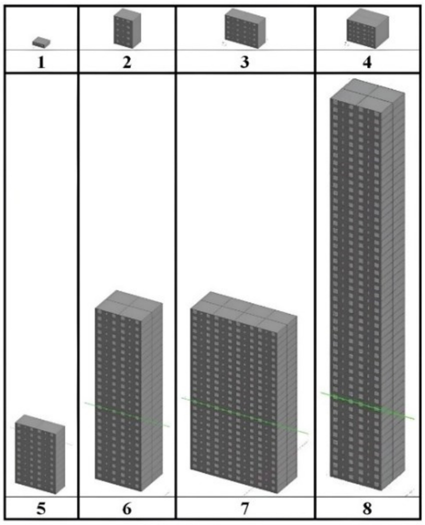

Figure 3. Schematic representation of the eight building scenarios considered in this study, illustrating variations in the number of floors and block configurations (Details are described in Table 1).

Table 1. Specifications of the eight modeled scenarios, including building names, number of floors, and block configurations, employed in this study.

Scenario No.	Name	No. of blocks	No. of floors	No. of units/floor	No. of common walls
1	200 × 1 × 1	200	1	1	0
2	40 × 5 × 1	40	5	1	2
3	20 × 5 × 2	20	5	2	3
4	10 × 5 × 4	10	5	4	4
5	10 × 10 × 2	10	10	2	3
6	2 × 25 × 4	2	25	4	4
7	1 × 25 × 8	1	25	8	5
8	1 × 50 × 4	1	50	4	4

In all scenarios, a standardized building with a floor area of approximately 100 m^2 was modeled, the layout of which is presented in Figure 4.

3. Different Climate Scenarios

The building scenarios described previously were simulated and systematically analyzed under three contrasting climatic conditions, represented by the Iranian cities of Yazd (hot), Arak (moderate), and Shahr-e Kord (cold). This approach enables a comprehensive assessment of the influence of climate variability on both building energy performance and occupant thermal comfort. Table 2 provides the recent average temperature and humidity data for these locations, serving as key inputs for the simulation models and ensuring that the analysis accurately reflects local environmental conditions. By incorporating these climatic parameters, the study captures the interaction between building design, HVAC system performance, and local weather, facilitating a nuanced evaluation of energy demand and comfort outcomes across diverse residential typologies.

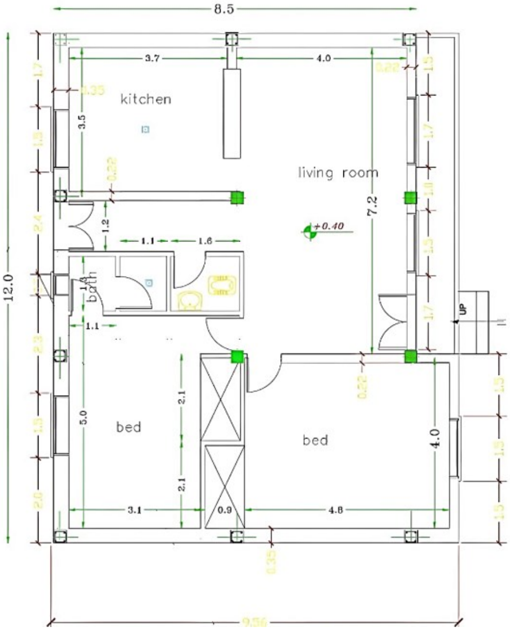

Figure 4. Layout of a standardized 100 m^2 building used in all scenarios.

Table 2. Key climatic parameters of Arak, Shahr-e Kord, and Yazd across different seasons.

Climatic properties		Arak	Shar-e Kord	Yazd
Height above mean sea level (m)		1742	2045	1212
Summer conditions at 15:00	DB (°C)	35	33	40
	WB (°C)	16	18	18
	RH %	17	23	12
Summer conditions at 6:00	DB (°C)	-12	-14	-5
	RH %	79	81	71

4. Numerical Modeling

4.1. Equations

This study investigates energy consumption in eight distinct building scenarios, under conditions that maintain comparable levels of thermal comfort. The assessment of thermal comfort is conducted using the Fanger method as in Equation (1).

$$PMV = 0.303\times e^{-0.0208}\{M - W - 3.05\times10^{-3}\times[5733 - 6.99(M - W) - P_a] \tag{1}$$

$$-0\cdot42\left[(M - W) - 58\cdot15\right] - 1\cdot7\times10^{-5}\times\left(5867 - p_a\right) - 0\cdot0014M\times(34 - t_a) - 3\cdot96\times10^{-8}$$

$$\times f_{cl}[(t_{cl} + 273)^4 - (t_{mrt} + 273)^4] - f_{cl}h_c(t_{cl} - t_a)\}$$

where M is the metabolic rate (W/m^2), W is the effective mechanical power (W/m^2); p_a is the water vapor partial pressure (Pa); fcl is the clothing surface area factor; ta is the air temperature (°C) and Icl is the clothing insulation (m^2 K/W). The mentioned parameters are calculated as follows:

Here, M denotes the metabolic rate (W/m^2), W represents the effective mechanical power (W/m^2), p_a is the water vapor partial pressure (Pa), f_{cl} refers to the clothing surface area factor, t_{at} indicates the air temperature (°C), and I_{cl} denotes the clothing insulation (m^2·K/W). These parameters are determined as follows in Equations (2) to (6):

$$t_{cl} = 35.7 - 0.028(M - W) - R_{cl}\{39.6\times10^{-9} f_{cl}[(t_{cl} + 273)^4 - (t_{mrt} + 273)^4] + f_{cl}h_c(t_{cl} - t_a) \tag{2}$$

$$h_c = 2\cdot38(t_{cl} - t_a)^{0\cdot25}, \quad h_c = 12\cdot1\sqrt{v} \tag{3}$$

$$f_{cl} = 1 + 0\cdot2I_{cl} \quad I_{cl} \prec 0\cdot5clo \tag{4}$$

$$f_{cl} = 1\cdot05 + 0\cdot1I_{cl} \quad I_{cl} \succ 0\cdot5clo \tag{5}$$

$$M = \left(2\cdot06\times10^4\right)\times\dot{V}\left(F_{oi} - F_{oe}\right) \tag{6}$$

In this study, t_r indicates the mean radiant temperature (°C), var signifies the relative air velocity (m/s), and t_{cl} denotes the clothing surface temperature (°C), all of which influence occupant thermal comfort. Based on these parameters, the level of occupant dissatisfaction in each building is determined using the Apple index, offering a comprehensive evaluation of indoor comfort conditions. The Apple index is calculated as follows in Equation (7):

$$PPD = 100 - 95\exp\left[-\left(0\cdot03353PMV^4 + 0\cdot2179PMV^2\right)\right] \tag{7}$$

4.2. HVAC and modelling of the details

Conducting energy simulations for the proposed building scenarios and estimating both cooling and heating loads necessitate the specification of a comprehensive set of input parameters within DesignBuilder software. These inputs encompass building geometry, construction materials, occupancy patterns, internal heat gains, and HVAC system specifications, all of which significantly affect simulation accuracy and the reliability of energy performance predictions. The key parameters employed in this modeling process are summarized in Table 3, providing a detailed overview of the data used to generate precise and robust simulation outcomes.

The importance of these inputs becomes particularly evident when comparing high-rise and low-rise residential typologies. High-rise buildings, with their greater façade exposure, complex floor layouts, and vertical stacking of units, require careful specification of thermal properties, shading, and HVAC system performance to accurately capture energy demand and thermal comfort. In contrast, low-rise, detached dwellings benefit from simpler geometries and more uniform environmental conditions, allowing passive design strategies to have a more pronounced effect on reducing energy consumption. By integrating these detailed inputs into the simulation models, the study is able to evaluate the interplay between building design, climatic conditions, and system configurations, thereby informing strategies to optimize energy efficiency and enhance occupant comfort across diverse residential forms.

Table 3. Key parameters and inputs employed in the energy modeling of buildings in this study.

Parameter	Value
Occupancy (People/m^2)	0.11
Winter clothing (Clo)	1
Summer clothing (Clo)	0.5
Heating set point (°C)	22
Cooling set point (°C)	24
Glazing Type	Double 6mm/6mm Arg
Lighting power density (W/m^2-100 lux)	5
ACH	5
HVAC type	Fan coil unit
Heating	Natural gas
Cooling	Electricity
DHW	Same as HVAC

5. Results And Discussion

This section presents the simulation outcomes for the eight building scenarios, differentiated by floor numbers and block configurations, as illustrated in Figure 3 and summarized in Table 1. The results are evaluated under three distinct climatic conditions to examine the combined effects of building geometry, HVAC systems, and local climate on both energy consumption and occupant thermal comfort. Key performance indicators, including cooling and heating loads, Predicted Mean Vote (PMV), and the Apple index, are analyzed to provide a comprehensive understanding of how design variations impact overall building efficiency and indoor comfort levels.

The heating and cooling loads for the selected cities and building typologies are presented in Figures 5 and 6, respectively. The results reveal that Yazd experiences the highest cooling demands, whereas Shahr-e Kord exhibits the greatest heating requirements across all scenarios. Among the eight examined building scenarios, Scenario 1 consistently demonstrates the highest combined heating and cooling loads, while Scenario 7 records the lowest energy demand. Table 4 summarizes the percentage increase in heating and cooling loads relative to Scenario 7, showing that energy consumption may rise by up to 67.1% for cooling and 58.9% for heating.

These results highlight the critical role of building typology and configuration in shaping energy performance. High-rise buildings, with their extensive façade exposure, vertical stacking of units, and more complex internal layouts, generally exhibit higher heating and cooling demands compared to low-rise, detached dwellings, which benefit from simpler geometries and greater potential for passive design strategies. Furthermore, the variations in energy loads directly affect occupant thermal comfort, as buildings with higher loads may require more intensive HVAC operation to maintain desirable indoor conditions. Consequently, optimizing building design, floor arrangements, and HVAC systems is essential not only for reducing energy consumption but also for enhancing overall occupant comfort across diverse climatic contexts.

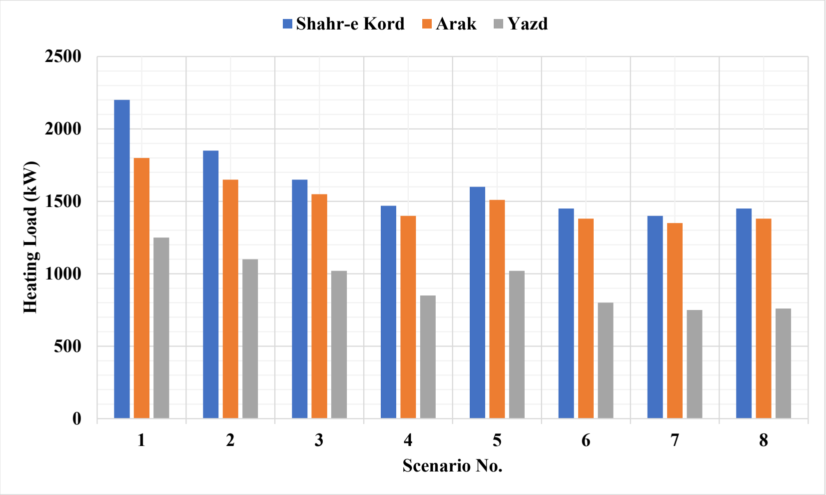

Figure4. Comparison of heating loads across the eight building scenarios in the three cities: Shahr-e Kord, Arak, and Yazd.

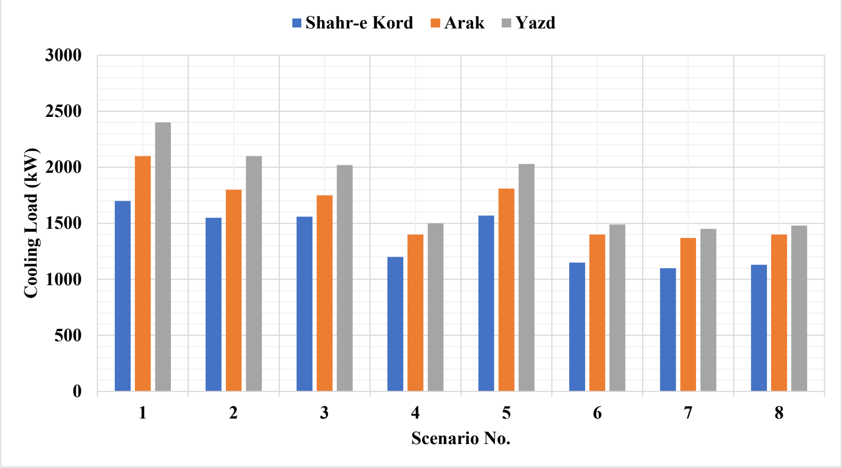

Figure 5. Cooling load in different cities across the eight scenarios.

Table 4. Details of name, number of floors and blocks of 8 different scenarios used in this paper.

Scenario No.	No. of common walls	Percentage of load difference (%)	
		Heating	Cooling
1	0	58.9	67.1
2	2	39.6	47.4
3	3	28.5	45.1
4	4	8.8	6.5
5	3	27.2	49.2
6	4	5.6	5.7
7	5	0	0
8	4	5.3	4.9

One of the most influential factors affecting heating and cooling loads across all scenarios is the number of common walls shared with adjacent units. Figure 7 illustrates the relationship between the number of shared walls and the resulting energy demand in Arak, showing that increased wall sharing reduces both heating and cooling loads by enhancing thermal insulation and minimizing the exposed surface area of the building envelope. The results demonstrate a clear inverse relationship: as the number of shared walls increases, energy consumption decreases. Specifically, Scenario 7, which incorporates the highest number of shared walls (five), exhibits the lowest overall load, whereas Scenario 1, with no shared walls, records the highest.

These findings have important implications for different building typologies. High-rise buildings, which often feature stacked units with multiple shared walls, can benefit from reduced energy demand due to increased thermal coupling between units, whereas low-rise, detached dwellings with minimal or no shared walls tend to experience higher heating and cooling requirements. Furthermore, variations in energy loads directly influence occupant thermal comfort, as buildings with higher loads require more intensive HVAC operation to maintain desirable indoor conditions. Consequently, careful consideration of unit configuration and wall-sharing strategies is critical in designing energy-efficient, comfortable, and sustainable residential developments across diverse climatic contexts.

Furthermore, calculating the comfort index provides valuable insight into the distribution of cooling and heating loads across the different scenarios with enhanced accuracy. Figure 8 illustrates the annual variation of the Fanger comfort index for all eight building scenarios. Although the index demonstrates broadly similar seasonal trends across scenarios, subtle variations between individual cases are evident, reflecting differences in building geometry, floor number, and block configuration. These variations align closely with the cooling and heating loads presented in Figures 4 and 5, highlighting the strong correlation between energy demand and occupant comfort. The results emphasize the importance of integrating thermal comfort analysis into the design process, offering guidance for architects and engineers to optimize building layouts, envelope design, and HVAC system performance to achieve both energy efficiency and high occupant comfort.

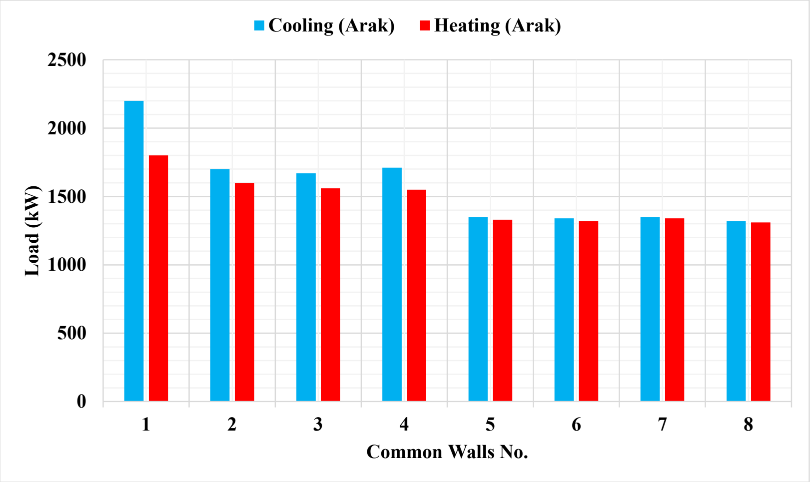

Figure 6. Variation of cooling and heating loads in Arak with respect to the number of walls shared between adjacent units.

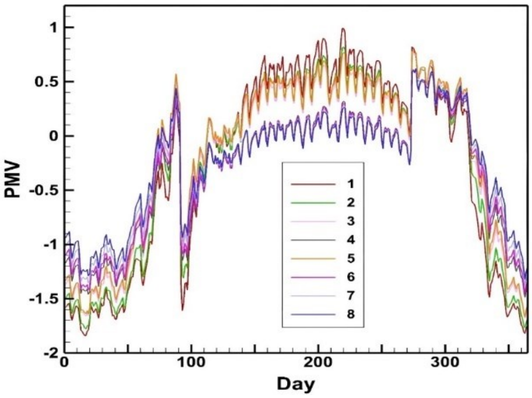

Figure 7. Comfort index (PMV) for all eight scenarios throughout 365 days of the year.

A central question in evaluating building energy performance is identifying which components contribute most significantly to heat loss under different scenarios. As shown in Figure 9, the majority of energy losses occur through the walls and roof. This effect is particularly pronounced in single-story flat buildings, where the roof accounts for a disproportionately large portion of total heat loss, thereby substantially increasing overall energy demand. In contrast, high-rise buildings, with multiple stacked floors and shared walls between units, typically exhibit reduced heat loss per unit due to decreased exposed surface area and increased thermal coupling between adjacent units.

These observations emphasize the importance of optimizing building envelope design, including wall and roof insulation, glazing selection, and orientation, to minimize energy consumption. Targeted improvements in these areas can significantly enhance thermal efficiency, reduce HVAC loads, and improve occupant comfort. Moreover, the findings suggest that design strategies should be adapted according to building typology, with particular attention to envelope performance in low-rise, detached structures and to façade optimization in high-rise developments, ensuring energy-efficient and sustainable residential solutions across diverse climates.

Given the recent disparities in energy consumption, the necessity of reducing electricity and gas usage has become increasingly evident. Figure 10 illustrates the breakdown of energy consumption across end-uses such as heating, cooling, lighting, and domestic hot water. Furthermore, Figures 11 presents the cumulative electricity and gas consumption for summer (cooling) and winter (heating) periods, respectively. As anticipated, this pattern is reflected in both heating and cooling load values: Scenario 1 exhibits the highest electricity and gas consumption, whereas Scenario 7 demonstrates the lowest energy demand. This trend highlights the influence of building design, floor configuration, and block arrangement on overall energy performance.

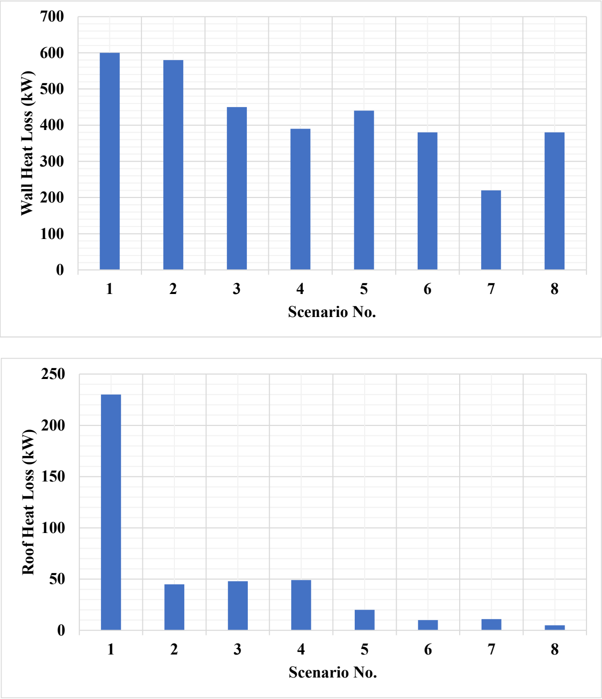

Figure 8. Comparative analysis of thermal losses through exterior walls and roof structures across the eight building scenarios.

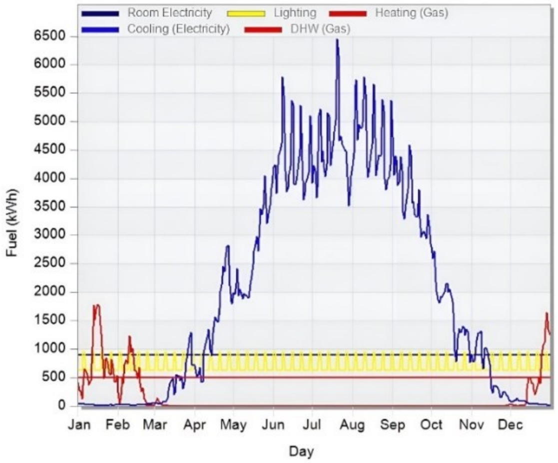

Figure 9. Composition of energy consumption by category, encompassing heating, cooling, lighting, and domestic hot water.

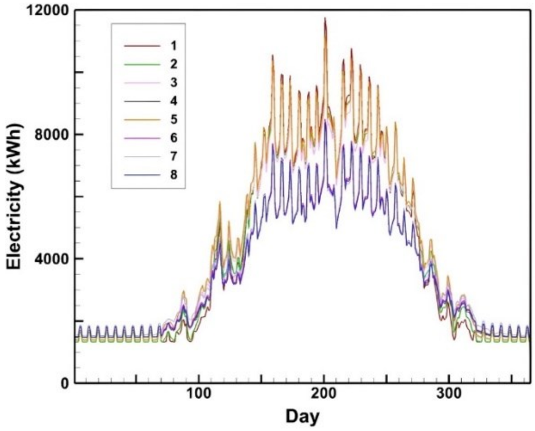

Figure 10. Cumulative electricity consumption in 365 days of the year (cooling) for eight scenarios.

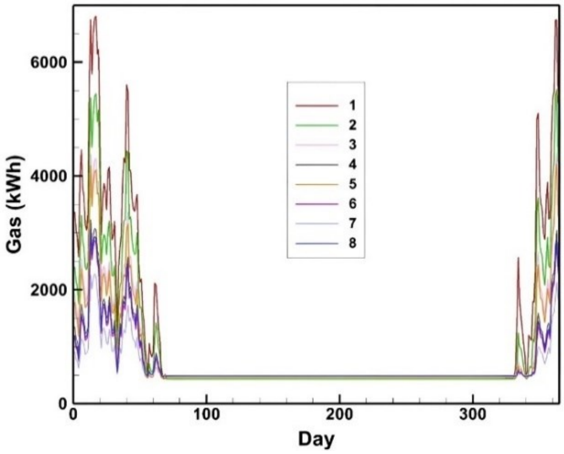

Figure 11. Cumulative gas consumption in 365 days of the year (heating) for eight scenarios.

Computational Fluid Dynamics (CFD) provides valuable insights into airflow behavior by revealing aspects that are not directly observable. Figures 12 and 13 illustrate the generated mesh, along with the pressure and velocity contours for the building in Scenario 8, taken as a representative case of all scenarios. As expected, in high-rise buildings, wind flow enhances heat transfer, a phenomenon that is consistent with and confirmed by the results presented in the preceding figures.

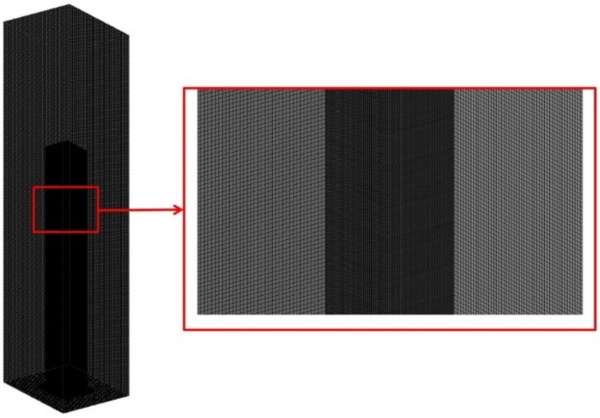

Figure 12. Example of the computational grid used for CFD simulations in this study.

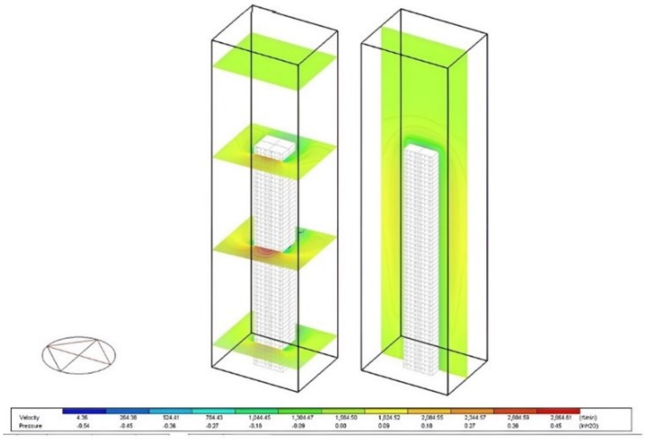

Figure 13. Pressure and velocity contours across various sections of the building for Scenario 8.

Overall, the results indicate that high-rise scenarios, which maximize the number of shared walls, can reduce heating and cooling energy consumption by nearly 60% across the examined cities.

6. Conclusion

This study analyzed and compared the cooling and heating energy consumption of high-rise and low-rise buildings, using the Fanger comfort index as the primary criterion for assessing thermal comfort. Energy demand for both heating and cooling was evaluated across eight distinct building scenarios, which differed in floor count and block configuration, under three representative climatic conditions corresponding to the Iranian cities of Yazd (hot), Arak (moderate), and Shahr-e Kord (cold). Simulations were conducted using DesignBuilder software to provide a detailed assessment of building performance. The scenarios included a range of building types, from single-story independent units to high-rise structures with up to 50 floors, as illustrated in Figure 3 and summarized in Table 1.

The results demonstrate that building geometry, floor configuration, and block arrangement significantly influence both energy consumption and thermal comfort. High-rise buildings with fewer shared walls and larger exposed surfaces tend to exhibit higher heating and cooling loads, whereas designs incorporating shared walls and optimized block layouts reduce energy demand while maintaining occupant comfort. These findings underscore the importance of integrating energy-efficient design strategies with climate-responsive planning to achieve sustainable and comfortable residential developments across diverse urban contexts.

The results demonstrated that the number of shared walls has a more significant influence on energy performance than the number of floors. Specifically, single-story buildings without shared walls exhibited up to 58.9% higher heating loads and 67.1% higher cooling loads compared to scenarios with greater wall adjacency. On average, the difference in energy consumption between the buildings with the maximum and minimum number of common walls was approximately 60%. Moreover, heat loss through the roof of a one-story building was found to be nearly 30 times greater than that of high-rise buildings with multiple units (Figure 9).

Additionally, exterior façade simulations were performed and analyzed to further assess their impact on energy performance. Future research will focus on examining the potential of phase change materials in reducing energy consumption in both high-rise and low-rise buildings.

Nomenclature

A	Surface area (m^2)	*V*	Volume of space (m^3)
ACH	Air changes per hour (1/h)	*W*	Mechanical work (W/m^2)
Clo	Clothing insulation unit (clo)	*WB*	Wet bulb temperature (°C)
DB	Dry bulb temperature (°C)	*n*	Number of floors
E	Total energy consumption (kWh)		
L	Energy loss (kWh)	Greek	
M	Metabolic rate (W/m^2)	η	System efficiency (-)
PMV	Predicted Mean Vote (thermal comfort index) (-)	ρ	Density (kg/m^3)
Q	Heat transfer (W)		
RH	Relative humidity (%)	Subscripts	
T	Temperature (°C or K)	*a*	Air
U	Overall heat transfer coefficient (U-value) ($W/(m^2 \cdot K)$)	*w*	Wall

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, have been completely observed by the authors.

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