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Evaluation of the Impact of a Brick Double-Skin Facade's Shading Device on Building Thermal Loads

Mohammad Hassan Abedini

abedini746@gmail.com

Shahrood University of Technology

Research Article

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Abstract

This study investigates the impact of brick shading devices—specifically perforated brick walls used in double-skin façades—on the heating and cooling loads of low-rise residential apartment buildings. The research focuses on two distinct climatic zones locatet in iran: Tehran (a cold semi-arid climate) and Bandar Abbas (a hot and humid climate). Employing a quantitative research methodilogy, thermal simulations were conducted using DesignBuilder software to assess the influence of these shading elements on indoor thermal comfort. The case study was modeled on a residential plot in both cities, serving as a pilot scenario. The design of the perforated brick façade was inspired by both contemporary applications and traditional Iranian brickwork patterns. Simulation results revealed that, in Tehran, the proposed façade increased the total energy load by 2.8% compared to the baseline model. Conversely, in Bandar Abbas, the same design led to a 4.7% reduction in total energy load. These findings highlight the potential of brick shading strategies in optimizing thermal performance, particularly in hot and humid regions, and offer valuable insights for climate-responsive façade design in low-rise residential architecture.

1. Introduction

One of the primary goals of architecture is to create healthy and comfortable spaces for occupants. Given the diverse climatic conditions across Iran, there is a growing need for region-specific environmental designs. In response to this need and advances in technology, innovative solutions have been proposed for building façade design with the aim of minimizing heat loss, providing effective shading, and enhancing thermal comfort for building occupants. Among these solutions, double-skin façade technology has been introduced as an effective strategy for controlling the interaction between the external and internal environments of apartment buildings (Mousavi et al., 2023; Yum, 2020).

To improve thermal comfort, it is crucial to implement solutions that involve designing apartments with appropriate techniques, including consideration of solar energy and thermal insulation (Facelli Sanchez et al., 2024). Furthermore, integrating shading systems can increase energy savings (Ascione et al., 2021).

In addition, porous brick walls, one of the most popular architectural elements in buildings, are used for maintaining privacy, providing shading, and improving ventilation in spaces (Omidvari & Omidvari, 2021; Trimble & Walkowicz, 2023). The use of these walls in residential buildings significantly impacts thermal comfort, with this effect being linked to the simultaneous transfer of heat and moisture through the bricks, which is a key aspect of residential apartment design and can enhance occupant comfort (Maděra et al., 2016).

Therefore, the aim of this research is to evaluate the impact of brick shading devices (perforated brick walls) in double-skin façades on heating and cooling loads in apartment buildings. The study focuses on two distinct climates: Tehran and Bandar Abbas. The building was modeled using DesignBuilder software (version 7.2), and simulations were conducted to assess the appropriate settings for each

shading device and internal blinds, along with their associated heating and cooling loads for single-skin and double-skin façades. The results of these simulations are compared to determine the most effective design.

2. Literature Review

Double-skin façades (DSFs) are considered advanced systems in architectural design that, by creating an intermediary layer between indoor and outdoor environments, play a critical role in climate control, energy loss reduction, thermal comfort enhancement, and visual quality improvement (Yum, 2020; Dong et al., 2024; Zheng et al., 2024). The performance of these systems varies significantly across different climates, making climate-responsive design essential for their optimal utilization.

In cold climates, the ventilated cavity between the two glass layers helps reduce heat loss and efficiently harness solar energy. Case studies from cold regions of China demonstrate that appropriate design strategies—such as south-facing box windows—can result in up to 60% energy savings (Zhou & Chen, 2010; Liu et al., 2023). In hot and humid climates, although DSFs alone may not fully meet thermal demands, when integrated with suitable materials, optimal orientation, and transparency control, they can reduce cooling loads, enhance natural ventilation, and improve daylighting performance (Yellamraju, 2004; Shameri et al., 2011).

In hot and arid climates, DSFs combined with shading devices enable natural ventilation through the stack effect, reduce direct solar gain, and improve thermal performance (Hamza, 2008). Shading systems installed within the cavity—especially in high-rise buildings—effectively lower cooling demands and maintain indoor comfort (Gratia & De Herde, 2007). CFD simulations have shown that parameters such as cavity depth, louver material, and optical properties significantly influence system efficiency (Parra et al., 2015). Moreover, integrated modeling indicates that adjustable seasonal shading devices can reduce energy consumption throughout the year; specifically, adjusting louver angles between **30° and 90°** can lead to 0.4–6.4% annual energy savings (Baldinelli, 2009; Lee et al., 2015).

In addition to contemporary approaches, traditional structures such as brick shading **screens or** perforated walls have long been employed in hot and dry regions. Constructed from porous bricks, these elements reduced direct solar penetration while serving as thermal insulators that contributed to indoor cooling (Heydari & Zare, 2022). Often combined with materials like wood, plaster, or tiles, these vernacular components not only provided shading but also facilitated airflow and surface cooling, thereby enhancing indoor comfort (Jasim et al., 2021; Al-Asadi et al., 2024; Amirabadi et al., 2021; Hamid, Mohson et al., 2021).

Today, reviving and integrating traditional principles through modern technologies can offer effective solutions to improve thermal performance, especially in hot and arid environments.

Table 1
Review of related literature

Reference	Year	Research Objective	Methodology	Evaluated Indicators	Key Findings
Al Dakheel & Tabet Aoul	2017	Comprehensive review of active shading systems	Literature review	System type, cost, energy use, daylight	Active systems can reduce cooling energy by up to 50%.
El Semary et al.	2017	Development of modern responsive mashrabiyas	Design analysis + ethnography	Daylight, responsive tech, identity	Mashrabiya can serve as a smart shading system in modern architecture.
Vazquez	2017	Formal analysis of perforated brick walls in Paraguay	Form analysis + algorithmic modeling	Ventilation, shading	Proposed a generative grammar for perforated brick patterns.
Hraska	2018	Classification of adaptive solar shading systems	Literature review	Glare, adaptability	Adaptive systems outperform traditional ones depending on goals.
Chi Pool	2019	Evaluation of thick perforated facades for visual comfort	Multi-factor analysis + DIVA simulation	UDI, perforation %, thickness	Optimized geometry significantly improves daylight performance.
Aljawder & El-Wakeel	2019	Visual performance of traditional mashrabiya in Bahrain	Field study	Natural light, uniformity, glare	Reduced glare and improved light distribution indoors.
Lim et al.	2020	Optical and cooling performance of shading in Korean homes	Simulation + field measurement	Cooling load, illuminance	Egg-crate performed best for solar control and energy saving.
Brancaleoni et al.	2021	Angular light transmission in perforated brick walls	Radiance + lab testing	Solar angle, daylight levels	Sharp reduction in transmission at 55–65°; perforation ratio unreliable alone.
Heidari et al.	2021	Fixed shading devices in hot-dry residential buildings	Energy simulation with Ecotect	Energy demand, daylight levels	Certain fixed types best suited to reduce

Reference	Year	Research Objective	Methodology	Evaluated Indicators	Key Findings
					heat gain and ensure daylight.
Bagasi, Calautit, & Karban	2021	Integrating traditional mashrabiya for natural ventilation	Experimental + simulation	Indoor temp, airflow, fluctuations	Open mashrabiya lowered temp by 2.4°C; thermal performance improved.
Mangkuto et al.	2021	Optimizing adaptive/fixed shading for tropical facades	Annual daylight simulation	sDA, ASE, orientation, slat angle	Adaptive design essential for east/west facades; orientation critical.
Bagasi (PhD Thesis)	2022	Thermal and ventilation performance of mashrabiya	Field study + CFD + evaporative cooling	Room temp, louver angle, cooling method	Wet fabric and optimized louvers reduced temps up to 7.5°C.
Taki & Kumari	2023	Energy and cultural role of mashrabiya in Saudi Arabia	Survey + case study + simulation	Operative temp, solar gain, privacy	Cooling load reduced, daylight improved, but cultural knowledge lacking.
Trimble & Walkowicz	2023	Structural design of perforated masonry walls	Code analysis + engineering guidelines	Wind load, structural detailing	Design standards needed for structural safety of perforated walls.
Mahdavinejad et al.	2024	Effect of facade geometry on energy and visual comfort	Parametric modeling + NSGA-II	Daylight, glare, energy use	Tilted facades balanced daylight quality and energy use.
Byun et al.	2024	Control strategies for daylight dimming in open-plan offices	Simulation of control logic	DGP, curtain setting, sensor angle	Covered sensors optimized glare control; uncovered not recommended.
Jiang et al.	2024	Impact of dynamic PVSDs on daylight and energy use	Parametric design + Ladybug	Energy savings, UDI, control mode	Up to 50.38% energy savings; combination mode most efficient.

Reference	Year	Research Objective	Methodology	Evaluated Indicators	Key Findings
Mousavi et al.	2024	Shading devices in hot-arid office buildings (Kerman, Iran)	EnergyPlus + OpenStudio	Annual energy, shading type	Movable + fixed combo saved 40.29 GJ annually.
Pérez-Carramiñana et al.	2024	Movable solar shades in Mediterranean climate	Simulation + field + surveys	Thermal comfort, daylight distribution	Cooling demand dropped by 60%; adjustable shades ensured uniform daylight.
Sahebzadeh et al.	2024	Wind energy harvesting through ducted facade openings	CFD + neural network modeling	Nozzle angle, power density	Optimal geometry increased power density up to 35.5x.
Alelwani et al.	2025	Optimizing daylight and energy in traditional “Roshan”	Numerical simulation + Genetic Algorithm	Energy use, UDI, blade thickness/angle	Energy reduced by 16.6%; optimal dimensions proposed for varied climates.

3. Methodology

3.1. Location of the cases

To evaluate the performance of the proposed façade design under different climatic conditions and to develop a practical recommendation, it was deemed appropriate to simulate the design in two distinct climates: Tehran and Bandar Abbas in iran.

Tehran

For the simulation process, the EPW weather file (2009–2023) for Tehran was imported into DesignBuilder. This file is available for download from the One Building website (Climate.onebuilding.org). Tehran Province, whose capital is the city of Tehran—the capital of Iran—covers an area of approximately 12,981 square kilometers and is located between 34° to 36.5° north latitude and 50° to 53° east longitude. The city's elevation ranges from 1,100 meters above sea level in the south, 1,200 meters in central parts, and up to 1,700 meters in the northern areas. Tehran experiences cold and dry winters with very low temperatures, while the summers are relatively warm. According to the Köppen–Geiger climate classification, Tehran is categorized under the cold semi-arid climate (BSk) (Peel et al., 2007).

Bandar Abbas

For the simulation process, the EPW weather file for Bandar Abbas (updated from 2009 to 2023) was imported into DesignBuilder. This file can be downloaded from the One Building website (Climate.onebuilding.org). Bandar Abbas, the capital of Hormozgan Province, is located in southern Iran, approximately 1,050 kilometers south of Tehran. The city lies at geographic coordinates of approximately 27.17°N latitude and 56.26°E longitude, with an elevation ranging from 0 to 20 meters above sea level. Bandar Abbas experiences mild and dry winters, while summers are extremely hot and humid due to its coastal location and subtropical climatic conditions. According to the Köppen–Geiger climate classification system, Bandar Abbas is categorized as having a hot desert climate (BWh) (Peel et al., 2007; Valizadeh & Khoorani, 2020).

3.2. Description of the case studies and Assumptions

The case study building consists of five floors and five residential units. It occupies a land area of 111 m², with a floor height of 2.94 meters for each unit. The internal spaces include conditioned zones such as the living room, kitchen, and bedrooms, as well as unconditioned spaces like the bathroom, toilet, and stairwell. The only façades capable of receiving solar radiation are located on the southern, southeastern, and eastern sides of the building. Figure 3 illustrates the floor plan and 3D model of the reference unit. Table 3 presents the physical properties (structure, thermal conductivity, specific heat capacity, and density) of the materials used in the building envelope.

3.3. Methods

The objective of this study is to evaluate the impact of porous brick shading devices on the thermal load of buildings utilizing such façade systems. It addresses the following research questions:

- How does the use of porous brick shading devices as a sustainable and passive solution affect heating and cooling energy demand?
- In which of the two climates—hot desert (BWh) in Bandar Abbas or cold semi-arid (BSk) in Tehran—do these shading systems perform more effectively?

This study follows a systematic approach with four key stages, as outlined below:

Step 1. Review of Previous Research: The investigation begins with a comprehensive review of existing literature to analyze the climate and architectural characteristics of buildings that resemble those in the study area.

Step 2. Baseline Building Simulation: In this phase, the selected building is modeled and simulated using Design Builder software to establish a baseline performance.

Step 3. Integration of Perforated Brick Shading System: A perforated brick shading device is integrated into the simulation model, with various parameters being adjusted to explore its impact on the building’s performance.

In this study, the thermal performance of a building is evaluated using the advanced simulation capabilities of *Design Builder* software (version 7.2). To validate the Design Builder software, the *Energy Plus Testing with ANSI/ASHRAE Standard 1402001 (BESTEST)* procedure was employed. The Test Case 600 model was selected based on the specified conditions and simulated using Design Builder version 7.2. The simulation results showed a deviation of less than 10% compared to the benchmark values provided in the standard documentation, indicating an acceptable level of validation (Ashrae, 2001).

As a powerful graphical interface integrated with the *Energy Plus* simulation engine, Design Builder enables detailed analysis of a building's energy consumption patterns. Its flexibility allows for application throughout various stages of the architectural design process, providing comprehensive performance data that support the refinement and optimization of building designs. This tool is particularly effective during the early design phases, where proactive evaluations can inform and guide decision making, ultimately contributing to improved energy efficiency and overall building performance from the initial stages of project development (Abedini et al., 2024)

This holistic approach ensures that the brick porous shading devices contribute to energy savings without causing undesirable increases in thermal loads.

Table 2
Comparison of Simulation Results with Standard Data

(Source: Software Output)

Type of Energy Consumption	Standard Results (kW)	Simulation Results (kW)	Difference (%)
Cooling System Energy	6.79	6.63	2.3
Heating System Energy	4.67	4.41	5.5

The porous brick shading device analyzed in this study is composed of bricks measuring 20×10×5 cm, strategically installed on the southern, southeastern, and eastern facades of the building. The design allows for adjustable spacing between the brick rows: during warm seasons, the bricks are arranged in a closed configuration with 15 cm spacing, while in colder seasons, they are spaced 25 cm apart in an open configuration. Additionally, the distance between the shading device and the window glazing varies —20 cm when closed and 10 cm when open.

In this study, the use of the perforated brick shading device and internal venetian blinds has been systematically programmed based on seasonal climatic conditions and energy optimization objectives. During the cold seasons, the brick shading device remains fully open throughout the day to maximize solar heat gain. Simultaneously, the internal venetian blind is set to the "on" position from 7:00 AM to 4:00 PM.

In contrast, during the hot seasons, to minimize heat ingress and reduce cooling loads, the brick shading device remains closed throughout the day, while the internal venetian blind remains continuously active.

Moreover, the thermostat setpoints are defined as 23°C for heating and 26°C for cooling.

The following table presents the key assumptions adopted in the thermal modeling process, conducted under two distinct climatic conditions: Tehran (BSk climate) and Bandar Abbas (BWh climate).

Table 3
Specifications of Building Envelopes

Component	Layers (from inside to outside)	Thickness (cm)	U-value ($W/m^2 \cdot K$)
Roof Assembly	Gypsum board	2	
	Air gap between ceiling and board	30	
	Concrete slab	30	
	Bituminous waterproofing layer	1	
	Total	-	**0.350**
External Wall Assembly	Interior plaster	2	
	Brick wall	10	
	Polystyrene insulation	2	
	Brick wall	10	
	Cement mortar	2	
	Total	-	**0.250**
Double Glazed Window	Inner glass layer	3 mm	
	Argon gas-filled space	13 mm	
	Outer glass layer	3 mm	
	Solar Heat Gain Coefficient (SHGC)	-	**0.764**
	Direct Solar Transmittance	-	**0.705**
	Visible Transmittance (VT)	-	**0.612**
	U-value (ISO 10292 / EN673)	-	**2.673**
	U-value used in simulation	-	**2.556**

4. Results and Discussion

Simulation results indicate that the application of passive strategies—such as porous shading devices—across various Iranian climates can significantly reduce building cooling loads. These shading systems, due to their adjustable openings and compatibility with internal blinds, enhance thermal performance throughout the year. Particularly in hot and humid climates like Bandar Abbas, the strategic integration of such elements can play a crucial role in achieving thermal comfort and reducing energy consumption. The findings of this study further confirm that the optimal combination of these two components can lead to a substantial reduction in cooling loads during the warmer seasons.

Tehran Climate

The results of the thermal simulations for the semi-arid climate of Tehran, as summarized in the table below, highlight the impact of passive element operation strategies on optimizing the building's cooling and heating loads.

- **Cooling Load**: To achieve the greatest reduction in cooling demand, it is recommended that the interior venetian blind remains active (on) throughout the entire day. Under this condition, the proposed design scenario results in a 7.9% decrease in cooling load compared to the base case.
- **Heating Load**: Conversely, in order to minimize heating load, it is more effective to keep the venetian blind inactive (off) between 7:00 AM and 4:00 PM, thereby allowing maximum solar gain during peak sunlight hours. According to this operational strategy, the proposed scenario shows a 13.66% increase in heating load compared to the base case.

Table 4. Summary of simulation results for Tehran climate

Design Scenario	Received Solar Radiation (kWh)	Cooling Load (kWh)	Cooling Load Reduction (%)	Heating Load (kWh)	Heating Load Increase (%)
Base Case with Internal Blind (ON)	5382	23772	0%	-	-
Base Case with Internal Blind (OFF, 7:00–16:00)	33893	-	-	23439	0%
Proposed Design A (Internal Blind ON)	6459	21903	7.9% ↓	-	-
Proposed Design B (Blind OFF, 7:00–16:00)	27353	-	-	26640	13.66% ↑

Bandar Abbas Climate

The results of the thermal simulations conducted for the hot and humid climate of Bandar Abbas, as summarized in the following table, highlight the impact of passive element utilization strategies on

optimizing building thermal loads.

- **Cooling Load**: To achieve maximum reduction in cooling load, it is recommended that the internal venetian blind remains in the “on” position throughout the entire day. Based on this assumption, the proposed scenario with the internal blind activated demonstrates a 4.7% reduction in cooling load compared to the baseline condition.
- **Heating Load**: To minimize heating load during colder periods, the optimal strategy involves keeping the internal blind in the “off” position between 7:00 a.m. and 4:00 p.m., thereby allowing greater solar gain. Under this scenario, the proposed configuration results in an 18.3% increase in heating load relative to the baseline

Table 5. Summary of Simulation Results for Bandar Abbas Climate

Design Scenarios	Solar Radiation (kWh)	Cooling Load (kWh)	Cooling Load Reduction (%)	Heating Load (kWh)	Heating Load Increase (%)
Base Case with Internal Blind (On)	4247	70001	0%	–	–
Base Case with Internal Blind (Off 7–16)	26379	–	–	131	0%
Proposed Design A (Blind On)	5742	66677	4.7%↓	–	–
Proposed Design B (Blind Off 7–16)	21171	–	–	155	18.3%↑

5. Conclusion

The results of this study indicate that the proposed perforated brick façade, when combined with internal louvered blinds, exerts a dual and climate-dependent effect on the building’s overall thermal load. An analysis of its performance in two distinct Iranian climates—Tehran's semi-arid and Bandar Abbas's hot-humid climate—revealed that the building's thermal response to this façade configuration varies significantly with climatic conditions.

In the semi-arid climate of Tehran, the application of the perforated brick façade along with internal louvered blinds resulted in a **7.9% reduction in cooling load**. However, this solution led to a 13.66% increase in heating demand, ultimately causing a 2.8% rise in total thermal load. This net increase can be attributed to factors such as reduced solar gain during cold seasons, limited absorption of passive heat, and ineffective ventilation in winter. Overall, in climates with colder winters, the heating demand tends to offset the thermal advantages of such a façade.

Conversely, the same façade configuration yielded different results in the hot-humid climate of Bandar Abbas. In this region, the use of the perforated brick façade led to a 4.7% decrease in cooling load. Despite an 18.3% increase in heating demand, the dominance of cooling energy consumption in this climate resulted in an overall 4.7% reduction in total thermal load. These findings suggest that in hot and humid environments, the benefits of reduced solar heat gain, enhanced natural ventilation, and improved passive cooling outweigh the relatively minor increase in heating requirements, rendering the façade thermally efficient for such contexts.

Based on these results, it can be concluded that the thermal performance of perforated brick façades is not only influenced by their form and material properties but also highly sensitive to the climatic characteristics of each region. Since this façade design draws inspiration from traditional Middle Eastern and southern Iranian architecture, it appears to be particularly effective in warm and humid climates similar to that of Bandar Abbas. Leveraging the thermal mass of brick materials and a porous design strategy, this façade type can function as a viable passive solution to reduce the energy demand of cooling and air-conditioning systems.

Ultimately, the findings underscore the importance of climate-responsive architectural design and the necessity for environmental adaptability in building envelopes. It is recommended that architects and designers, especially in regions with diverse climates, reconsider the use of indigenous and vernacular strategies through a scientific and technical lens. Such approaches not only reduce energy consumption but also enhance indoor environmental quality, improve occupant thermal comfort, and reduce reliance on mechanical systems.

6. Limitations and Future Work

A key limitation of this study lies in the simplification of user behavior and internal heat gains during simulations. The research was also restricted to annual energy loads without addressing hourly thermal comfort variations or daylight performance. Furthermore, the study focused on two representative cities, and broader climatic diversity within Iran and the Middle East remains unexplored.

Future studies are recommended to incorporate real-world monitoring, dynamic occupant schedules, and multi-objective optimization involving daylight, thermal comfort, and cost analyses. Moreover, hybrid configurations with smart shading systems and advanced material technologies could be explored to further enhance the adaptability and energy performance of such façades.

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Figures



Figure 1

Location of Tehran and Bandar abbas

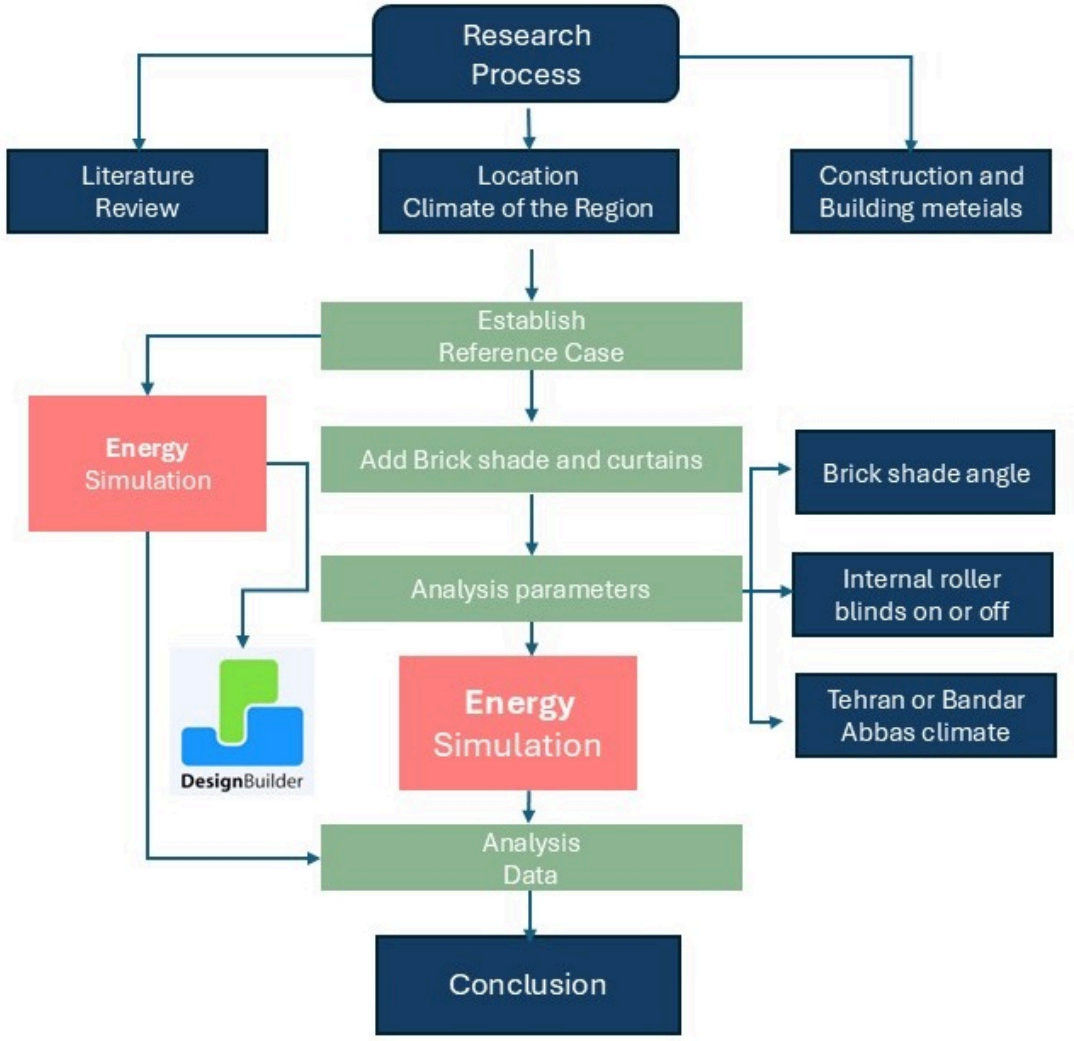


Figure 2

Research Method flowchart



Figure 3

a. Base case b. Brick shading device in closed mode, suitable for warm seasons c. Brick shading device in open mode, suitable for cold seasons

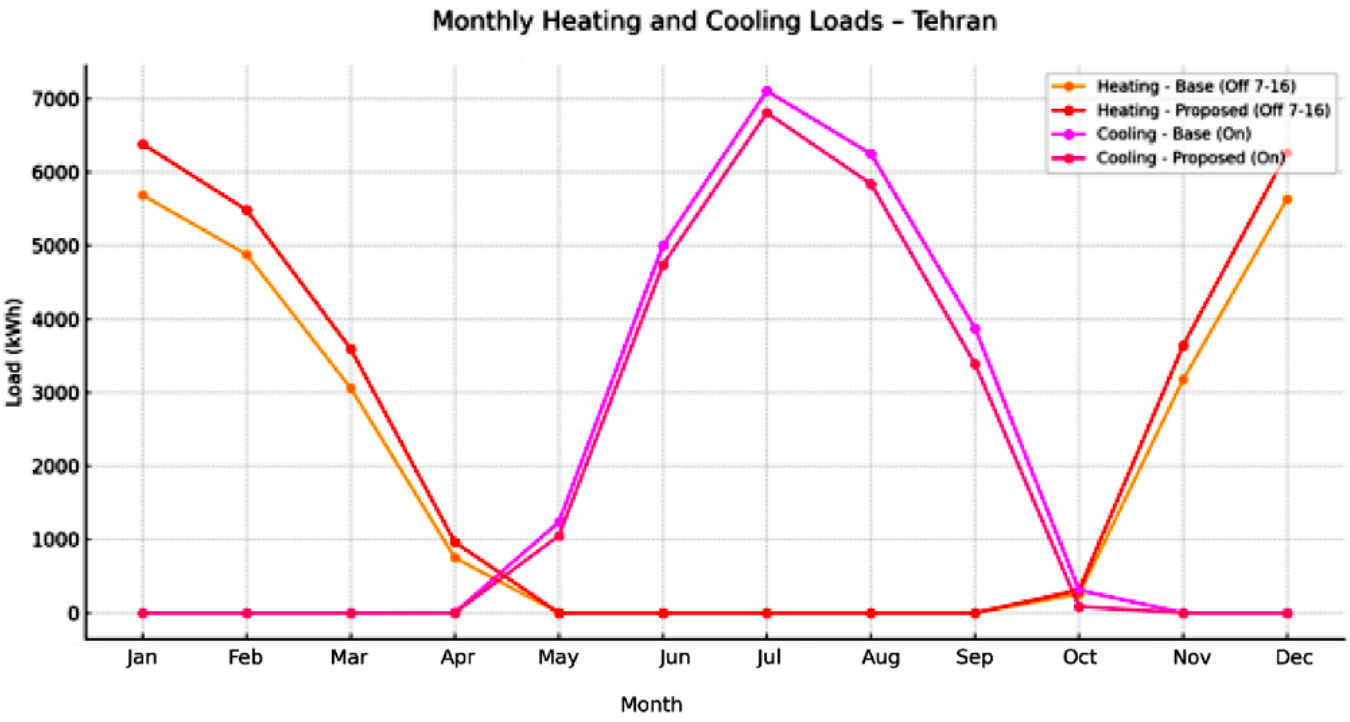


Figure 4

Monthly Heating and Cooling Loads – Tehran

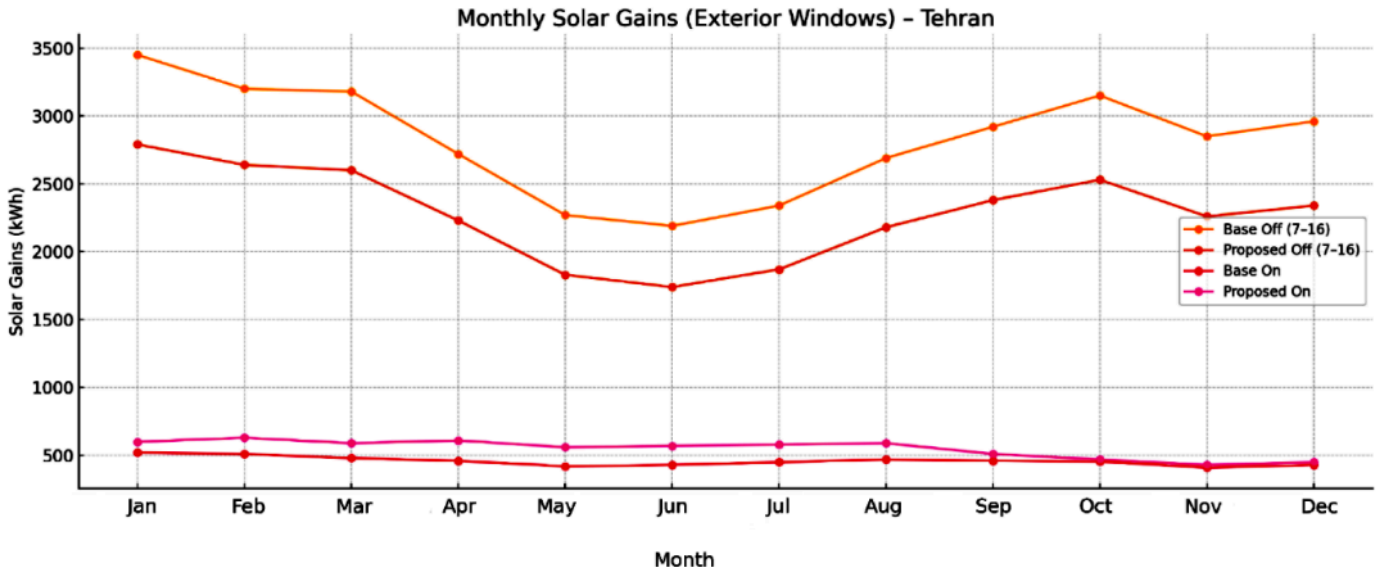


Figure 5

Monthly Solar Gains (Exterior Windows) – Tehran

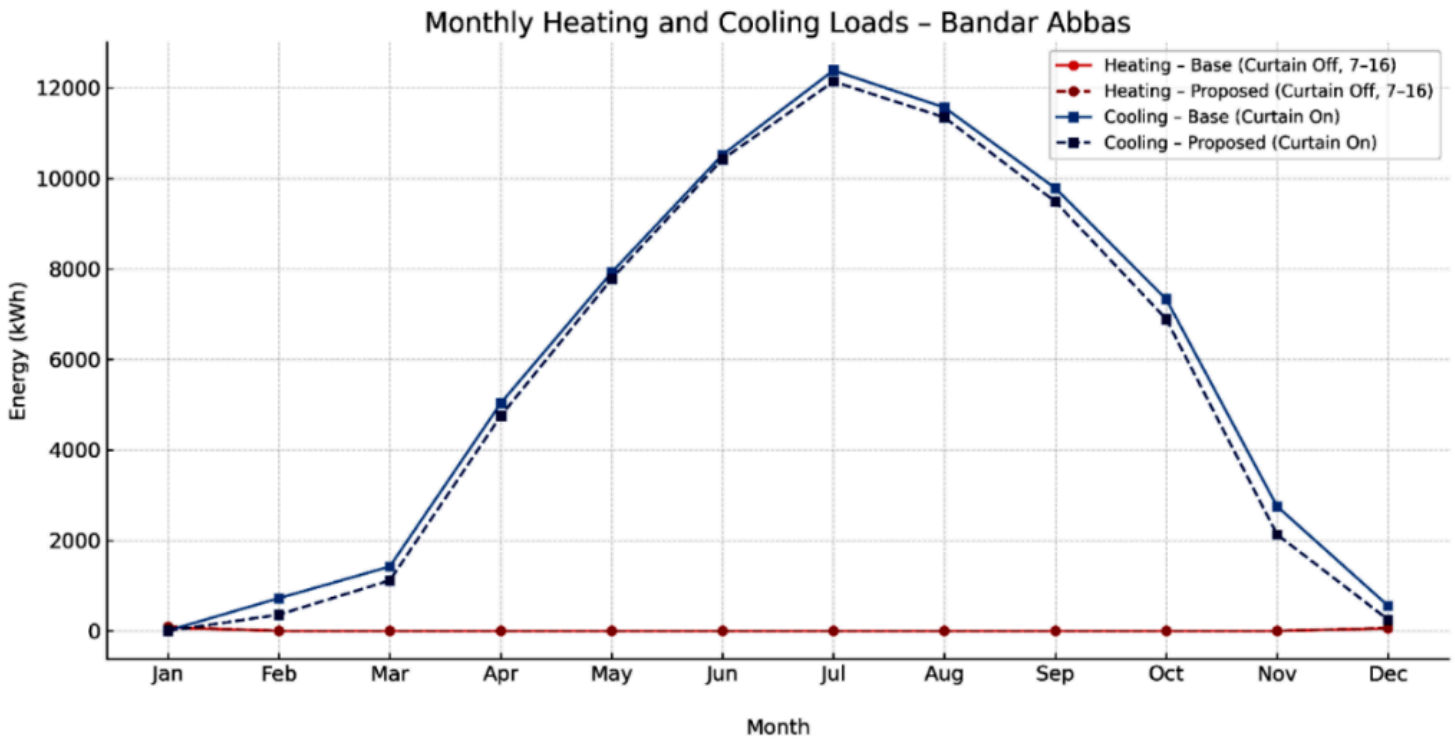


Figure 6

Monthly Heating and Cooling Loads – Bandar Abbas

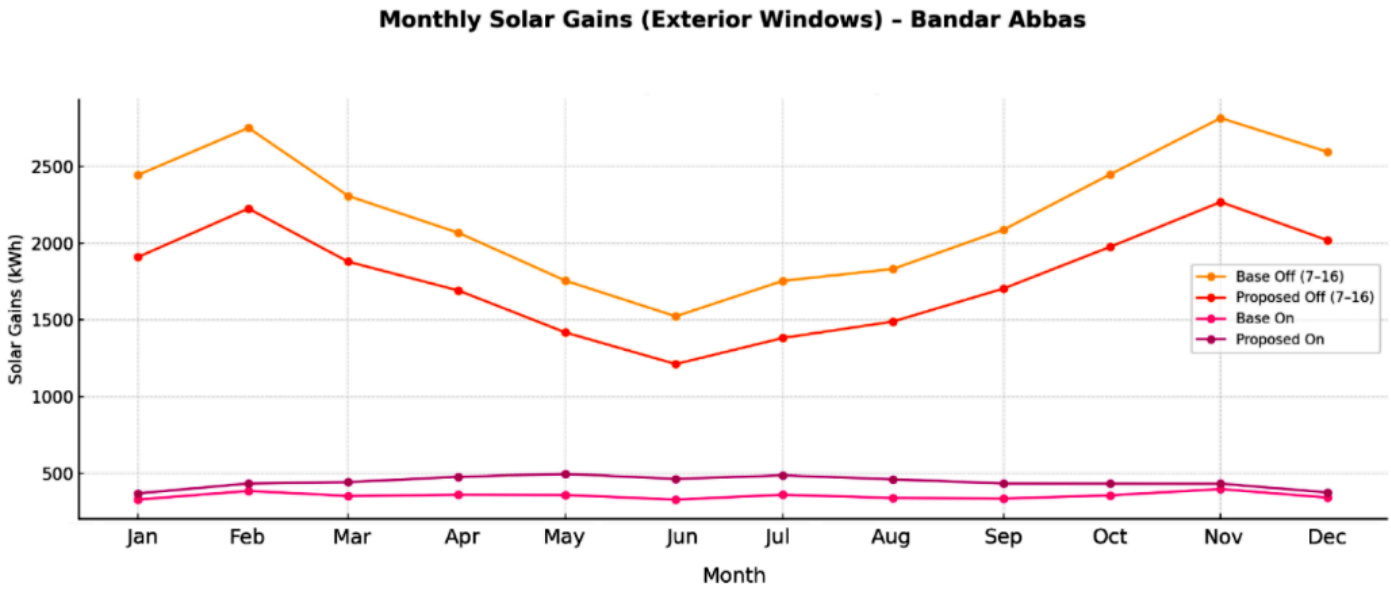


Figure 7

Monthly Solar Gains – Bandar Abbas