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Influence of Window-to-Wall Ratio, Orientation, and Glazing Type on Building Energy Performance across Climatic Zones in Afghanistan

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Abstract

The residential building sector is a significant contributor to global energy use and emissions, with window design playing a crucial role in thermal performance. In Afghanistan, where most housing is informal and energy infrastructure is limited, the absence of climate-responsive design practices has led to inefficient heating and cooling. Despite the proven effectiveness of passive strategies such as window optimization, little empirical research exists within Afghanistan's diverse climatic conditions. Therefore, this study investigates the combined impact of window-to-wall ratio (WWR), façade orientation, and glazing type on the energy performance of residential buildings across five cities representing a distinct climate classification. Using BEopt^{TM} simulation software integrated with EnergyPlus^{TM}, a standardized single-zone model was evaluated under multiple configurations: WWRs (0% - 70%), sixteen orientations, and three glazing types (single, double, triple). Heating and cooling demands were analyzed across four major climatic zones—cold-dry, cold semi-arid, hot semi-arid, and hot desert. The results reveal that while heating and cooling patterns follow a consistent directional trend across climates, the magnitude of energy variation differs significantly. Larger WWRs increase cooling loads regardless of glazing performance or orientation, indicating that window openings cannot effectively reduce cooling demand. However, in cold regions, south-facing façades (ENE to WSW) combined with moderate-to-high WWRs and high-performance glazing significantly reduce heating loads, offering up to 33% annual energy savings. In contrast, in hot regions like Kandahar and Farah, even high-performance glazing fails to compensate for the cooling penalties introduced by larger window areas, making minimal WWRs essential for energy-efficient design. This research contributes a data-driven foundation for climate-sensitive residential design in Afghanistan, providing localized guidance for architects and policymakers. It highlights the need for orientation-aware window optimization in cold climates and stringent WWR limitations in hot regions—an essential step toward developing national energy codes and advancing sustainable architecture in under-resourced contexts.

Keywords

Window-to-Wall Ratio, Energy Efficiency, Energy Simulation, Sustainability, Residential Buildings, Afghanistan

1. Introduction

1.1. Background

In recent decades, residential buildings have become one of the primary contributors to global energy consumption and greenhouse gas emissions, thus exacerbating environmental challenges and accelerating climate change [1]. This trend is further intensified by increasing urbanization, global population growth, and rising housing demands, all of which have led to higher construction rates and greater reliance on energy-intensive heating, cooling, and lighting systems [2]-[4]. According to the International Energy Agency, buildings account for nearly 40% of global energy use and approximately one-third of CO_2 emissions [5]. With people now spending an estimated 90% of their time indoors, especially in urban areas, the performance of the built environment directly affects both energy systems and human well-being [6].

In response, various strategies have been explored to enhance energy efficiency in buildings. These include enhancing thermal insulation, upgrading the building envelope, integrating renewable energy systems, and, most importantly, adopting passive design techniques. Passive solar design—through careful control of solar gains and natural ventilation—presents a particularly promising, cost-effective, and context-sensitive strategy [7]-[10]. By minimizing dependence on mechanical systems and utilizing climate-responsive features such as orientation, window placement, thermal mass, and shading devices, passive design significantly improves thermal comfort and reduces operational energy demand.

Among passive design features, window-related parameters are particularly influential due to their high thermal sensitivity. The size, orientation, glazing type, and surface area of windows—typically expressed as the window-to-wall ratio (WWR)—directly affect a building's heating, cooling, and lighting loads. An appropriately optimized WWR can enhance solar heat gain during winter, reduce thermal losses or unwanted gains during summer, and contribute to overall energy efficiency [11]-[13]. However, the relationship between WWR and energy performance is highly dependent on both climatic conditions and facade orientation. For example, in colder regions, larger south-facing windows may improve passive heating, while in hotter climates, reduced glazing on east and west facades is necessary to minimize solar gains.

In many developed countries, advancements in building technologies, supported by stringent energy efficiency regulations and well-enforced building codes, have fostered a gradual transition toward low-energy and net-zero buildings. However, in developing countries such as Afghanistan, these advancements remain largely absent. Afghanistan faces a complex interplay of challenges, including decades of conflict, poor governance, widespread poverty, and a fragile infrastructure sector [14] [15]. The country's energy system is severely constrained: electricity supply is limited, unreliable, and highly dependent on imports [16] [17]. With residential buildings consuming a disproportionate share of energy—mainly for space heating and cooling—households in Afghanistan frequently resort to using inefficient and environmentally harmful fuels such as wood, coal, diesel, and even waste materials [18]-[20]. This reliance exacerbates both environmental degradation and health risks, particularly during the winter season in densely populated urban centers.

Adding to this challenge is the unregulated and informal nature of urban growth in Afghanistan. Approximately 86% of the urban housing stock is classified as informal or slum housing, most of which lack the basic thermal performance characteristics necessary for energy efficiency or indoor comfort [21]. Despite the introduction of the Afghanistan Building Code (ABC) in 2012, the country still lacks enforceable, climate-responsive energy standards that could inform and guide residential construction [22]. Consequently, fundamental architectural parameters—such as building orientation, window placement, glazing type, thermal insulation, and shading—are routinely overlooked in the design and construction process [23]. This not only leads to excessive energy consumption but also perpetuates a reliance on active mechanical systems that many households cannot afford or adequately operate.

1.2. Literature Review

The importance of WWR in building performance has been confirmed by numerous studies across various climate zones and building typologies. Goia [24] found that in European mid-latitude climates, a WWR between 30% and 45% offered optimal performance, resulting in 5% - 25% energy savings. Kheiri [25] emphasized the importance of climate and orientation, recommending WWRs between 20% - 32% for minimizing HVAC loads across multiple Köppen classifications. In a residential context, Kim *et al.* [26] highlighted that increased WWR typically leads to higher energy demand, although strategic window placement—especially at mid-height—can moderate this impact. Pino *et al.* [27] demonstrated that reducing WWR from 100% to 20% in Chile significantly lowered energy use for heating and cooling, and Alghoul *et al.* [28] reported that variations in window area could alter annual energy consumption by up to 181% in buildings located in

Libya. These findings reinforce the necessity of climate-specific, orientation-sensitive window design to achieve energy efficiency.

Despite the well-documented impact of these parameters in global literature, Afghanistan remains critically under-researched in this regard. Existing studies are limited in scale and scope, often focusing on a single variable (such as orientation, insulation, or shading) or a single location (typically Kabul), with minimal attention paid to the interaction of design parameters across the country's diverse climatic zones [29]-[33]. This narrow focus restricts the applicability of findings to a national context, where environmental conditions vary significantly—from arid regions in the south and west to extremely cold highland areas in the northeast. Furthermore, there is a conspicuous absence of data-driven research that analyzes the combined effects of WWR, orientation, and glazing type on building energy performance in Afghanistan's residential sector [34]. This gap not only limits the development of localized energy codes but also hinders the ability of architects, planners, and policymakers to design buildings that are both energy-efficient and contextually appropriate.

In contrast to earlier studies, this research adopts a broader methodological approach, an expanded geographic scope, and a specific focus on the interaction of key passive design variables. Whereas most previous studies in the context of Afghanistan tend to examine design strategies in isolation or are limited to a single urban area, this study employs a comparative, simulation-based framework to evaluate the energy performance of window configurations across multiple climatic zones. The selected cities—Bamian (Dsb, 2550 m), Ghazni and Mazar-e-Sharif (BSk, 2219 m and 357 m), Kandahar (BSh, 1010 m), and Farah (BWh, 750 m)—span varied Köppen climates and elevations, reflecting Afghanistan's climatic diversity.

By analyzing a range of WWRs, glazing types, and facade orientations, the study produces a comprehensive dataset that enables climate-specific recommendations for improving residential energy efficiency. Furthermore, the integration of multiple passive design parameters within a unified analysis aligns the research with contemporary best practices in climate-responsive architecture and addresses a critical lack of empirical data needed to support sustainable building design in Afghanistan.

The findings aim to support energy-conscious residential design guidelines adaptable to Afghanistan's diverse climatic and socio-economic conditions. Given widespread affordability challenges, limited energy access, and environmental pressures, passive solar design offers a practical, low-cost solution to improve thermal comfort. Additionally, considering the unplanned nature of most Afghan cities, the study provides data applicable to both new construction and retrofit projects, bridging the gap between global knowledge and local needs to promote resilient, sustainable architecture in an under-researched region.

2. Methods

This study employs a dynamic, simulation-based approach to evaluate the influence of WWR, façade orientation, and glazing type on the energy performance of residential buildings across diverse climatic conditions in Afghanistan. The analysis focuses on five representative cities—Bamian, Ghazni, Mazar-e-Sharif, Kandahar, and Farah—which are selected for their distinct geographic locations and climatic characteristics. The objective is to derive climate-responsive design recommendations by identifying optimal WWR configurations under varying environmental conditions.

Energy simulations were performed using BEopt™, a building energy modeling software. The simulation outputs were post-processed and analyzed using Microsoft Excel, which was also used to generate graphical illustrations of the results.

A simplified prototype model was developed, consisting of a square-shaped room with an attached bathroom. This geometry was selected for its directional neutrality and suitability for comparative analysis across different orientations. To isolate the impact of façade orientation and WWR, only one façade included fenestration elements (a door and a window), while the remaining three façades were modeled as fully opaque. The fenestrated façade was rotated in 22.5˚ increments, covering all 16 orientations (cardinal, intercardinal, and secondary intercardinal directions), as illustrated in Figure 1**.** For each orientation, the WWR varied incrementally from 0% to 70%, and each configuration was tested under three glazing types: single, double, and triple glazing. The thermal specifications for each glazing type are summarized in Table 1.

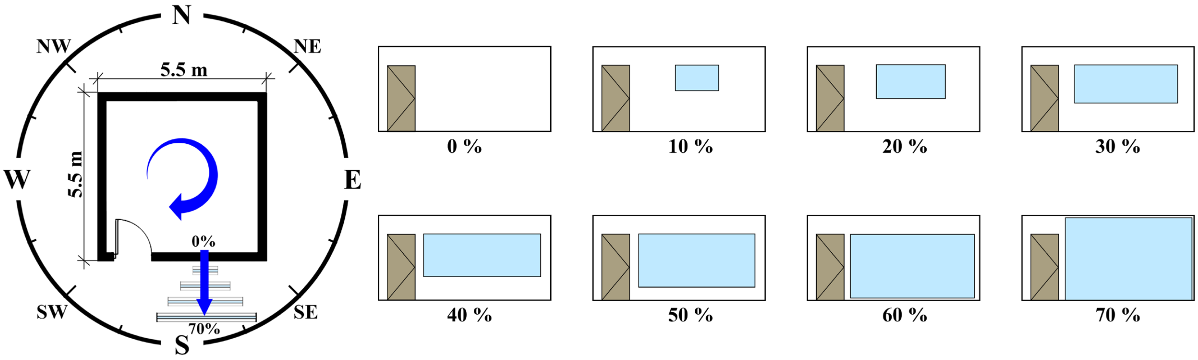


Figure 1. Simulation model setup: orientation, rotation, and window-to-wall ratio configurations.

To ensure methodological consistency and isolate the effects of the primary variables, all other building characteristics—including internal loads, occupancy schedules, material properties, insulation levels, and ventilation rates—were held constant across all simulations.

The simulation results were analyzed to determine the optimal WWR for each combination of orientation and glazing type, based on minimizing total annual energy consumption (heating and cooling combined). This approach facilitates the development of context-specific passive design guidelines for improving energy efficiency in residential buildings across Afghanistan's varied climatic regions.

Table 1. Thermal specifications of glazing types.

Glazing Type	U-Value (W/m²·K)	SHGC	Description
Single	4.77	0.63	Clear glass, non-metal frame
Double	2.78	0.56	Clear glass with air gap, non-metal frame
Triple	1.70	0.38	Low-E glass with air gap, high solar gain frame

2.1. Simulation Tool

Building Energy Simulation (BES) tools play a vital role in the evaluation and optimization of building energy performance across various design stages [35]. Their widespread application in both research and industry has led to continual development and the emergence of several specialized platforms. For this study, BEopt^{TM} (Building Energy Optimization Tool) version 2.8.0.0 was employed to simulate the energy performance of residential buildings. BEopt is specifically designed for modeling and optimizing energy use in residential settings, aiming to identify cost-effective design strategies that reduce energy consumption and support the transition toward low- or net-zero energy buildings [36] [37].

Developed by the National Renewable Energy Laboratory (NREL) in support of the U.S. Department of Energy's Building America Program, BEopt offers a user-friendly interface and a comprehensive library of predefined inputs, enabling the modeling and simulation of both new and retrofit residential structures—including single-family and multi-family dwellings. The tool facilitates energy analysis through various simulation modes, including single-building evaluations, parametric sweeps, and cost-based optimizations.

A key feature of BEopt is its integration with EnergyPlus^{TM}, the Department of Energy's flagship simulation engine, which provides detailed, hour-by-hour assessments of building energy use [38]. BEopt's simulation protocols are aligned with the Building America Housing Simulation Protocols, ensuring consistency and reliability in its analytical framework. The software considers a wide range of building parameters, such as geometry, orientation, thermal properties, occupancy schedules, and utility tariffs.

2.2. Building Geometry and Envelope Configuration

Given the significant variability in spatial arrangements and passive architectural strategies across different geographic and climatic contexts, this study adopts a standardized and simplified prototype model to ensure methodological consistency. The simulation model consists of a single square-shaped room (5.5 m × 5.5 m) with an attached bathroom, which serves as a representative and fundamental spatial unit found in many residential buildings across Afghanistan. The internal ceiling height is set at 2.75 meters, in alignment with commonly used residential construction standards in the region.

This simplified configuration allows for a controlled environment in which to isolate and assess the individual and combined effects of WWR, glazing type, and façade orientation on energy performance. To minimize the influence of solar radiation entering from multiple directions, only one façade of the model includes fenestration—a window and a door—while the remaining three façades are modeled as fully opaque. This design ensures that any variations in energy performance can be attributed specifically to the orientation and fenestration of the single exposed façade.

Construction materials and assemblies for the walls, roof, and floor were selected based on typical building practices in Afghanistan, which are increasingly used in new contemporary buildings. These assemblies reflect common construction methods and thermal characteristics used in local residential buildings. The composition and thickness of each construction layer are outlined in **Table 2**, presented in sequence from the exterior to the interior, to ensure transparency and replicability of the simulation assumptions.

Table 2. Building envelope characteristics and thermal specifications for the simulation model.

Characteristics	Unit	Properties
Floor Area	m^2	30
Ceiling height	m	2.75
Walls	-	Stucco 2.5 cm + R-5 Extruded Polystyrene Insulation (XPS) – 2.54 cm + Hollow Concrete Masonry Unit (CMU) 20 cm + Drywall 1.6 cm
	R-Value	0.036 + 0.9 + 0.936 + 0.1 = 1.972 m^2 K/W
Roof-(flat)	-	Medium Color Terracotta tiles + R-30C Fiberglass Batt - 23.5 cm + Drywall 1.6 cm
	R-Value	0.005 + 5.508 + 0.1 = 5.613 m^2K/W
Floor	-	Whole slab R10, R5 Gap XPS – 10 cm + 100% Carpet
	R-Value	1.8 + 0.374 = 2.174 m^2K/W
Door	-	Wood
	m^2	1.85
	U-Value	2.72 W/m^2K

2.3. Thermal Comfort Assumptions and Simulation Inputs

Thermal comfort, defined as the state of satisfaction with the thermal environment, is influenced by a combination of environmental and personal factors, including air temperature, humidity, air velocity, mean radiant temperature, clothing insulation, and metabolic activity [39]. While thermal comfort is inherently subjective, air temperature remains the most widely used indicator in both practice and research. According to the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), the operative temperature range recommended for maintaining comfort is 20˚C - 23.5˚C during the winter and 23˚C - 26˚C during the summer [40]. These thresholds were adopted as reference points in this study to establish consistent heating and cooling setpoints across all simulations. To reflect local cultural practices in Afghanistan—particularly the use of full-body traditional clothing—the heating set-point was set at 20˚C, and the cooling setpoint at 24.4˚C. These values align with both international standards and regional comfort expectations.

The thermal setpoints, internal loads, airflow assumptions, and HVAC system specifications used in the simulations are summarized in Table 3.

Air infiltration, representing uncontrolled airflow through the building envelope, was modeled at a rate of 1 ACH50 (air changes per hour at 50 Pascals of pressure differential). Although achieving this level of airtightness is challenging in most contemporary residential buildings in Afghanistan due to limited access to insulation materials and poor construction detailing, it was adopted as a standard assumption to ensure consistency across simulation scenarios. This airtightness level may influence the magnitude of reported energy demands; however, it allows the analysis to isolate the effects of the studied variables—WWR, orientation, and glazing—on overall building energy performance.

Table 3. Thermal simulation parameters: setpoints, internal gains, ventilation, and HVAC system specifications.

Characteristics	Unit	Properties
Cooling Set Point	˚C	24.4
Heating Set Point	˚C	20
	Internal Loads	
Occupancy	Person	1.5
Sensible Heat Gain	kJ/Person/h	232
Latent Heat Gain	kJ/Person/h	173
	Airflow	
Air Leakage	ACH50	1
Natural Ventilation	-	Year-round
	Space Conditioning	
Air Conditioner	EER	8.5
Electric Baseboard	Efficiency	100%
Ceiling Fan	-	National average

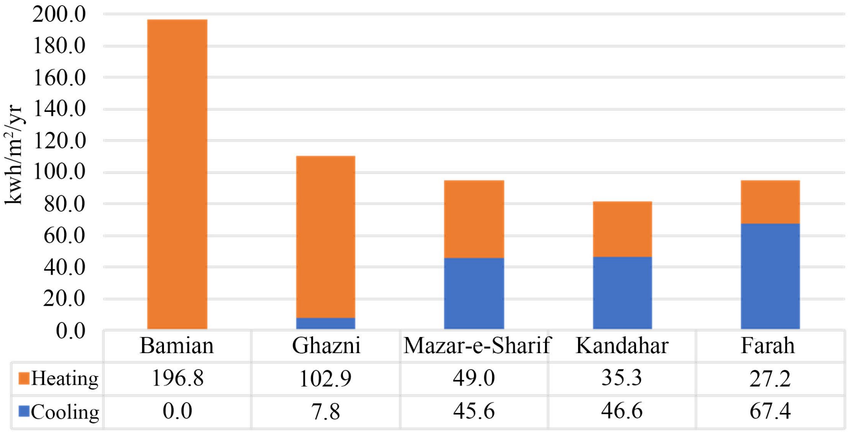
Internal heat gains were limited to occupant-related loads only, excluding contributions from lighting, appliances, and plug loads. Sensible and latent heat gains from occupants were modeled according to ASHRAE 2009 standards [41], based on an assumed occupancy of 1.5 persons for 16.5 hours per day—reflecting typical occupancy patterns in compact residential settings.

Space conditioning systems were standardized across all simulations. An electric baseboard heater with 100% energy efficiency was used for space heating, while space cooling was provided by an air conditioner with an average Energy

Efficiency Ratio (EER) of 8.5. Additionally, a ceiling fan was included to support indoor air circulation during the cooling season. All conditioning systems were powered by electricity, ensuring a uniform basis for comparing energy consumption across the different building configurations.

2.4. Baseline Model Definition

A baseline scenario with 0% WWR was simulated to establish a reference point. The model employed an opaque envelope with only a door, thereby minimizing heat exchange through openings and isolating the intrinsic climatic demands of each location (**Figure 2**). The results show distinct regional variations: Bamian and Ghazni experience high heating demand with negligible cooling, Kandahar and Farah exhibit the reverse pattern, and Mazar-e-Sharif demonstrates a more balanced energy profile due to its transitional climate. This baseline provides a standardized foundation for systematically evaluating the influence of design parameters—such as WWR, orientation, and glazing type—on building energy performance.



	Bamian	Ghazni	Mazar-e-Sharif	Kandahar	Farah
🟧Heating	196.8	102.9	49.0	35.3	27.2
🟦Cooling	0.0	7.8	45.6	46.6	67.4

Figure 2. Baseline scenario: annual energy demand across various cities at 0% WWR.

2.5. Location and Climatic Condition

Afghanistan, a mountainous and landlocked country located at the intersection of South and Central Asia, is characterized by its diverse geography and complex topography. The country encompasses a wide range of landscapes, including fertile river valleys, arid deserts, high plateaus, and rugged mountain ranges. The eastern part of the country is dominated by the Hindu Kush and Pamir Mountain ranges, with elevations reaching up to 7485 meters. These mountains not only define Afghanistan's striking physical geography but also act as climatic and cultural barriers, separating the northern provinces from the central and southern regions [42].

The country's climate exhibits considerable spatial and temporal variability, with sharp diurnal and seasonal temperature fluctuations, limited precipitation, and high solar radiation throughout the year. For example, summer temperatures in high-altitude cities such as Ghazni and Kabul can vary from near freezing at night to over 30˚C during the day, while lowland regions such as Farah and Kandahar may experience daytime temperatures exceeding 45˚C with minimal nighttime cooling [43]. Clear skies dominate for more than 300 days annually, highlighting the potential for integrating passive solar design strategies into Afghanistan's buildings [44].

To effectively evaluate the influence of WWR on energy performance in Afghanistan, this study selected five cities that represent the major climatic conditions found across the country (**Figure 3**). Given the absence of detailed national climatic zoning or building-specific climate data, the Köppen-Geiger climate classification system was adopted to guide the city selection [45] [46]. This system categorizes regions based on long-term temperature and precipitation patterns and provides a practical framework for differentiating climatic zones in data-scarce contexts like Afghanistan.

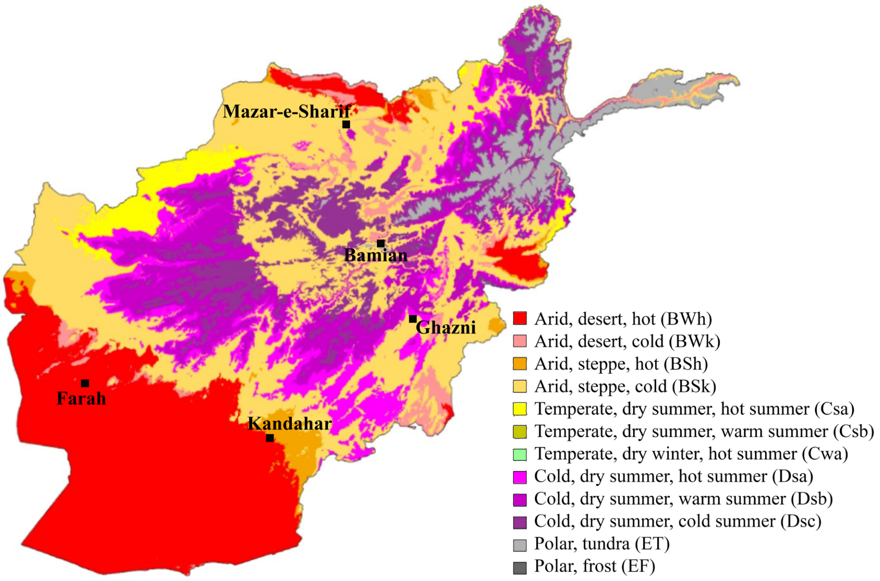


Figure 3. Köppen-Geiger climate map of Afghanistan [46].

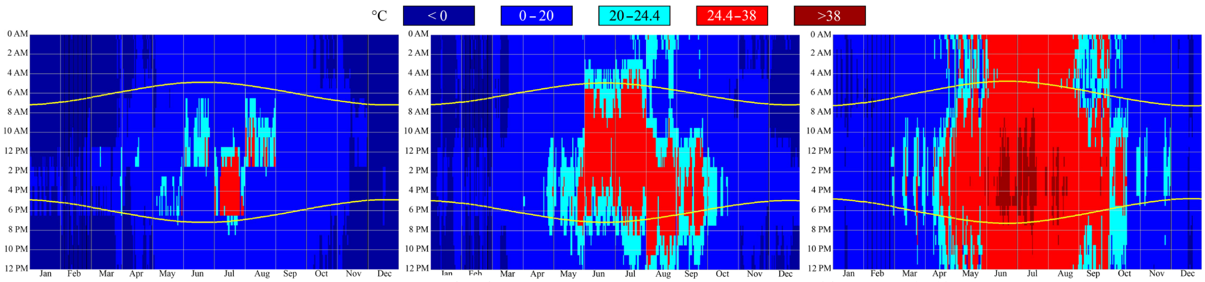
Table 4. Climate classification, elevation, and temperature profiles of selected cities.

Köppen climate type	City	Elevation (m)	Average annual temp. (˚C)	
			Min.	Max.
Dsb	Bamian	2550	1.3	14.3
BSk	Ghazni	2219	6.9	19.6
	Mazar-e-Sharif	357	14.1	24.3
BSh	Kandahar	1010	13.1	27.6
BWh	Farah	750	14.7	29.9

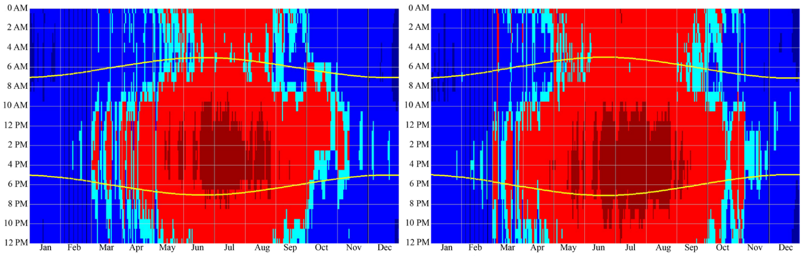
To represent the diverse climatic conditions of Afghanistan, five cities were selected based on the Köppen-Geiger climate classification system, each corresponding to a distinct climatic zone (**Figure 3** and **Table 4**). These include Bamian (Dsb), Ghazni and Mazar-e-Sharif (BSk), Kandahar (BSh), and Farah (BWh). While most zones are represented by a single city, two cities—Ghazni and Mazar-e-Sharif—were intentionally selected from the BSk (cold semi-arid) category due to the extensive spatial coverage and climatic variability of this zone across the country. Despite sharing the same classification, these two cities exhibit substantial differences in altitude and thermal conditions: Ghazni, situated at a higher elevation, is characterized by colder winters, whereas Mazar-e-Sharif, located in the northern lowlands, experiences significantly hotter and drier summers. The inclusion of both cities within the BSk category enables a more nuanced analysis of how regional and microclimatic variations affect building energy performance.

The selected cities span a wide range of latitudes (31.6˚ to 36.5˚N) and elevations (357 m to 2550 m), encompassing climates from cold, dry-summer continental (Dsb) to hot desert (BWh). This geographic and climatic spread offers a robust basis for evaluating how different environmental conditions affect the performance of passive design strategies, particularly in relation to WWR.

To illustrate the climatic variations among these cities, **Figure 4** and **Figure 5** present the average daily and monthly outdoor temperature profiles throughout the year. **Figure 4** presents the average hourly outdoor temperature profiles for the selected cities across an annual cycle. These profiles clearly demonstrate seasonal and daily temperature dynamics. For instance, Bamian experiences extended sub-zero conditions during winter, while Farah endures persistent high temperatures exceeding 40˚C in summer. Even within the same Köppen class, cities like Ghazni and Mazar-e-Sharif show contrasting patterns due to differences in elevation and regional influences. These findings underscore the necessity of tailoring energy-efficient building design to local climatic conditions rather than relying solely on broad climate categories.



(a) Bamian (b) Ghazni (c) Mazar-e-Sharif



(d) Kandahar (e) Farah

Köppen climate type of the cities:

(a) Cold, dry summer, warm summer (*Dsb*)
(b) Arid, steppe, cold (*BSk*)
(c) Arid, steppe, cold (*BSk*)
(d) Arid, steppe, hot (*BSh*)
(e) Arid, desert, hot (*BWh*)

Figure 4. Average daily temperature of the selected cities [47] [48].

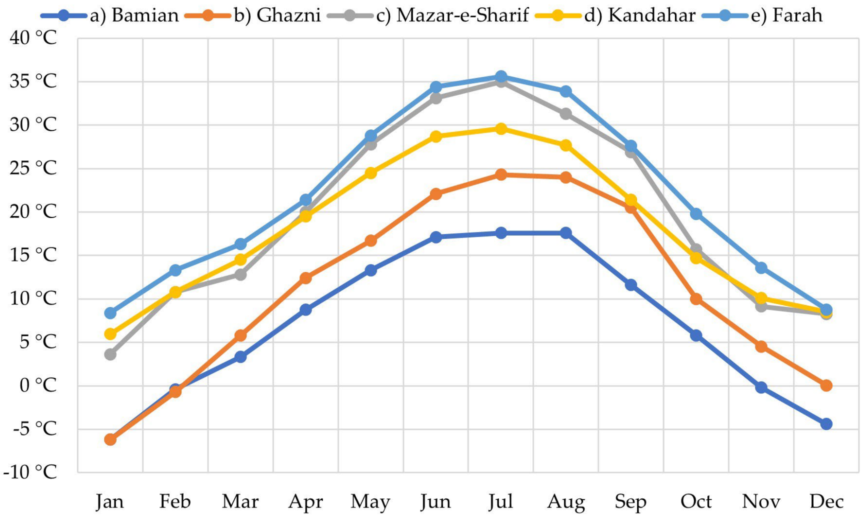


Figure 5. Monthly average outdoor temperatures for the selected cities.

3. Results and Discussion

This section presents the results illustrating the impact of WWRs, façade orientations, and glazing types on annual cooling, heating, and total energy consumption across five climatically diverse cities in Afghanistan: Bamian (Dsb), Ghazni and Mazar-e-Sharif (BSk), Kandahar (BSh), and Farah (BWh).

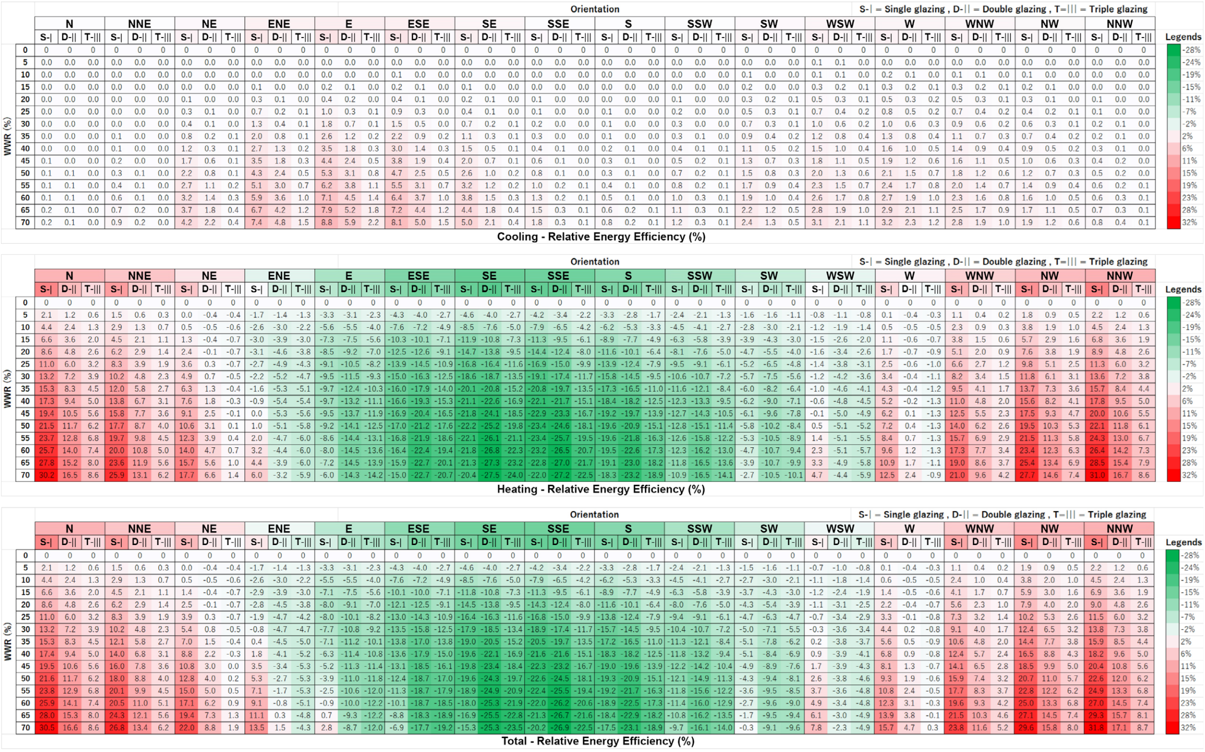
To facilitate interpretation and practical application, results are visualized using heatmaps. Each matrix represents energy performance across WWR increments (vertical axis) and sixteen cardinal orientations (horizontal axis). Within each cell, three glazing types—single (S-|), double (D-||), and triple (T-|||)—are represented by standardized symbols. Values indicate the percentage change in energy demand relative to the baseline (0% WWR): positive values denote increased consumption; negative values indicate savings.

A multi-layered color-coding system enhances readability. The primary gradient transitions from deep red (highest energy penalty) through white (neutral) to dark green (maximum savings), scaled to the magnitude of change. Orientation headers adopt a secondary color scheme reflecting their aggregate energy performance, enabling rapid identification of favorable or unfavorable orientations. Additionally, glazing markers are tinted to reflect relative performance within specific orientation-WWR combinations.

3.1. Cold, Dry, and Warm Summer (Dsb) Climate—Bamian

Figure 6 illustrates a comprehensive heatmap analysis of the relative energy performance of a residential building in Bamian, situated in Afghanistan’s cold, dry-summer climate zone (Dsb). The analysis is divided into three sections: cooling energy efficiency (top), heating energy efficiency (middle), and total annual energy efficiency (bottom), each evaluated across varying WWRs, glazing types, and façade orientations.

Despite Bamian’s low cooling requirements, the top heatmap table indicates a consistent decline in cooling energy efficiency with increasing WWR across all orientations and glazing types. This trend is especially evident on east- and west-facing façades, which receive intense solar radiation during morning and afternoon hours. Single-glazed windows exhibit the most pronounced increase in cooling loads, while double and triple glazing offer modest mitigation. The underlying reason is that transparent surfaces permit higher solar heat gains compared to opaque walls, which are more effective at insulating against external thermal conditions.



Orientation

S-| = Single glazing , D-|| = Double glazing , T=||| = Triple glazing

WWR (%)	N			NNE			NE			ENE			E			ESE			SE			SSE		
	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.2	0.1	0.0	0.2	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.3	0.1	0.0	0.4	0.2	0.0	0.4	0.1	0.0	0.2	0.1	0.0	0.1	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.1	0.0	0.7	0.2	0.1	1.0	0.3	0.1	0.9	0.3	0.0	0.4	0.1	0.0	0.1	0.0	0.0
30	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.1	0.0	1.3	0.4	0.1	1.8	0.7	0.1	1.5	0.5	0.0	0.7	0.2	0.1	0.2	0.0	0.0
35	0.0	0.0	0.0	0.1	0.0	0.0	0.8	0.2	0.1	2.0	0.8	0.1	2.6	1.2	0.2	2.2	0.9	0.2	1.1	0.3	0.1	0.3	0.0	0.0
40	0.0	0.0	0.0	0.1	0.0	0.0	1.2	0.3	0.1	2.7	1.3	0.2	3.5	1.8	0.3	3.0	1.4	0.3	1.5	0.5	0.1	0.4	0.1	0.0
45	0.1	0.0	0.0	0.2	0.0	0.0	1.7	0.6	0.1	3.5	1.8	0.3	4.4	2.4	0.5	3.8	1.9	0.4	2.0	0.7	0.1	0.6	0.1	0.0
50	0.1	0.1	0.0	0.3	0.1	0.0	2.2	0.8	0.1	4.3	2.4	0.5	5.3	3.1	0.8	4.7	2.5	0.5	2.6	1.0	0.2	0.8	0.1	0.0
55	0.1	0.1	0.0	0.4	0.1	0.0	2.7	1.1	0.2	5.1	3.0	0.7	6.2	3.8	1.1	5.5	3.1	0.7	3.2	1.2	0.2	1.0	0.2	0.1
60	0.1	0.1	0.0	0.6	0.1	0.0	3.2	1.4	0.3	5.9	3.6	1.0	7.1	4.5	1.4	6.4	3.7	1.0	3.8	1.5	0.3	1.3	0.2	0.1
65	0.2	0.1	0.0	0.7	0.2	0.0	3.7	1.8	0.4	6.7	4.2	1.2	7.9	5.2	1.8	7.2	4.4	1.2	4.4	1.8	0.4	1.5	0.3	0.1
70	0.2	0.1	0.0	0.9	0.2	0.0	4.2	2.2	0.4	7.4	4.8	1.5	8.8	5.9	2.2	8.1	5.0	1.5	5.0	2.1	0.4	1.8	0.3	0.1

WWR (%)	S			SSW			SW			WSW			W			WNW			NW			NNW		
	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.1	0.0	0.2	0.1	0.0	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.3	0.2	0.1	0.3	0.2	0.1	0.3	0.2	0.1	0.2	0.1	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.1	0.0	0.0	0.3	0.2	0.1	0.5	0.3	0.1	0.5	0.3	0.2	0.5	0.3	0.1	0.3	0.1	0.0	0.1	0.0	0.0
25	0.1	0.0	0.0	0.2	0.0	0.0	0.5	0.3	0.1	0.7	0.4	0.2	0.8	0.5	0.2	0.7	0.4	0.2	0.4	0.2	0.1	0.1	0.0	0.0
30	0.1	0.0	0.0	0.3	0.0	0.0	0.7	0.3	0.1	1.0	0.6	0.2	1.0	0.6	0.3	0.9	0.6	0.2	0.6	0.3	0.1	0.2	0.1	0.0
35	0.1	0.0	0.0	0.3	0.1	0.0	0.9	0.4	0.2	1.2	0.8	0.4	1.3	0.8	0.4	1.1	0.7	0.3	0.7	0.4	0.2	0.2	0.1	0.0
40	0.2	0.1	0.0	0.4	0.1	0.1	1.1	0.5	0.2	1.5	1.0	0.4	1.6	1.0	0.5	1.4	0.9	0.4	0.9	0.5	0.2	0.3	0.1	0.0
45	0.3	0.1	0.0	0.5	0.2	0.1	1.3	0.7	0.3	1.8	1.1	0.5	1.9	1.2	0.6	1.6	1.1	0.5	1.0	0.6	0.3	0.4	0.2	0.0
50	0.3	0.1	0.0	0.7	0.2	0.1	1.5	0.8	0.3	2.0	1.3	0.6	2.1	1.5	0.7	1.8	1.2	0.6	1.2	0.7	0.3	0.5	0.2	0.0
55	0.4	0.1	0.0	0.8	0.2	0.1	1.7	0.9	0.4	2.3	1.5	0.7	2.4	1.7	0.8	2.0	1.4	0.7	1.4	0.9	0.4	0.6	0.2	0.1
60	0.5	0.1	0.0	1.0	0.3	0.1	1.9	1.0	0.4	2.6	1.7	0.8	2.7	1.9	1.0	2.3	1.6	0.8	1.6	1.0	0.5	0.6	0.3	0.1
65	0.6	0.2	0.1	1.1	0.3	0.1	2.2	1.2	0.5	2.8	1.9	1.0	2.9	2.1	1.1	2.5	1.7	0.9	1.7	1.1	0.5	0.7	0.3	0.1
70	0.8	0.2	0.1	1.2	0.3	0.1	2.4	1.3	0.5	3.1	2.1	1.1	3.2	2.3	1.2	2.8	1.9	1.0	1.9	1.2	0.6	0.8	0.4	0.1

Cooling - Relative Energy Efficiency (%)

Orientation

S-| = Single glazing , D-|| = Double glazing , T=||| = Triple glazing

WWR (%)	N			NNE			NE			ENE			E			ESE			SE			SSE		
	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	2.1	1.2	0.6	1.5	0.6	0.3	0.0	-0.4	-0.4	-1.7	-1.4	-1.3	-3.3	-3.1	-2.3	-4.3	-4.0	-2.7	-4.6	-4.0	-2.7	-4.2	-3.4	-2.2
10	4.4	2.4	1.3	2.9	1.3	0.7	0.5	-0.5	-0.6	-2.6	-3.0	-2.2	-5.6	-5.5	-4.0	-7.6	-7.2	-4.9	-8.5	-7.6	-5.0	-7.9	-6.5	-4.2
15	6.6	3.6	2.0	4.5	2.1	1.1	1.3	-0.4	-0.7	-3.0	-3.9	-3.0	-7.3	-7.5	-5.6	-10.3	-10.1	-7.1	-11.9	-10.8	-7.3	-11.3	-9.5	-6.1
20	8.6	4.8	2.6	6.2	2.9	1.4	2.4	-0.1	-0.7	-3.1	-4.6	-3.8	-8.5	-9.2	-7.0	-12.5	-12.6	-9.1	-14.7	-13.8	-9.5	-14.4	-12.4	-8.0
25	11.0	6.0	3.2	8.3	3.9	1.9	3.6	0.3	-0.7	-2.7	-4.9	-4.3	-9.1	-10.5	-8.2	-13.9	-14.5	-10.9	-16.8	-16.4	-11.6	-16.9	-15.0	-9.9
30	13.2	7.2	3.9	10.2	4.8	2.3	4.9	0.7	-0.5	-2.2	-5.2	-4.7	-9.5	-11.5	-9.3	-15.0	-16.3	-12.5	-18.6	-18.7	-13.5	-19.1	-17.4	-11.7
35	15.3	8.3	4.5	12.0	5.8	2.7	6.3	1.3	-0.4	-1.6	-5.3	-5.1	-9.7	-12.4	-10.3	-16.0	-17.9	-14.0	-20.1	-20.8	-15.2	-20.8	-19.7	-13.5
40	17.3	9.4	5.0	13.8	6.7	3.1	7.6	1.8	-0.3	-0.9	-5.4	-5.4	-9.7	-13.2	-11.1	-16.6	-19.3	-15.3	-21.1	-22.6	-16.9	-22.1	-21.7	-15.1
45	19.4	10.5	5.6	15.8	7.7	3.6	9.1	2.5	-0.1	0.0	-5.3	-5.6	-9.5	-13.7	-11.9	-16.9	-20.4	-16.5	-21.8	-24.1	-18.5	-22.9	-23.3	-16.7
50	21.5	11.7	6.2	17.7	8.7	4.0	10.6	3.1	0.1	1.0	-5.1	-5.8	-9.2	-14.1	-12.5	-17.0	-21.2	-17.6	-22.2	-25.2	-19.8	-23.4	-24.6	-18.1
55	23.7	12.8	6.8	19.7	9.8	4.5	12.3	3.9	0.4	2.0	-4.7	-6.0	-8.6	-14.4	-13.1	-16.8	-21.9	-18.6	-22.1	-26.1	-21.1	-23.4	-25.7	-19.5
60	25.7	14.0	7.4	20.0	10.8	5.0	14.0	4.7	0.7	3.2	-4.4	-6.0	-8.0	-14.5	-13.6	-16.4	-22.4	-19.4	-21.8	-26.8	-22.3	-23.2	-26.5	-20.7
65	27.8	15.2	8.0	23.6	11.9	5.6	15.7	5.6	1.0	4.4	-3.9	-6.0	-7.2	-14.5	-13.9	-15.9	-22.7	-20.1	-21.3	-27.3	-23.2	-22.8	-27.0	-21.7
70	30.2	16.5	8.6	25.9	13.1	6.2	17.7	6.6	1.4	6.0	-3.2	-5.9	-6.0	-14.3	-14.2	-15.0	-22.7	-20.7	-20.4	-27.5	-24.0	-22.0	-27.2	-22.5

WWR (%)	S			SSW			SW			WSW			W			WNW			NW			NNW		
	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	-3.3	-2.8	-1.7	-2.4	-2.1	-1.3	-1.6	-1.6	-1.1	-0.8	-1.1	-0.8	0.1	-0.4	-0.3	1.1	0.4	0.2	1.8	0.9	0.5	2.2	1.2	0.6
10	-6.2	-5.3	-3.3	-4.5	-4.1	-2.7	-2.8	-3.0	-2.1	-1.2	-1.9	-1.4	0.5	-0.5	-0.5	2.3	0.9	0.3	3.8	1.9	1.0	4.5	2.4	1.3
15	-8.9	-7.7	-4.9	-6.3	-5.8	-3.9	-3.9	-4.3	-3.0	-1.5	-2.6	-2.0	1.1	-0.6	-0.7	3.8	1.5	0.6	5.7	2.9	1.6	6.8	3.6	1.9
20	-11.6	-10.1	-6.4	-8.1	-7.6	-5.0	-4.7	-5.5	-4.0	-1.6	-3.4	-2.6	1.7	-0.7	-0.9	5.1	2.0	0.9	7.6	3.8	1.9	8.9	4.8	2.6
25	-13.9	-12.4	-7.9	-9.5	-9.1	-6.1	-5.2	-6.5	-4.8	-1.4	-3.8	-3.1	2.5	-0.6	-1.0	6.6	2.7	1.2	9.8	5.1	2.5	11.3	6.0	3.2
30	-15.8	-14.5	-9.5	-10.6	-10.7	-7.2	-5.7	-7.5	-5.6	-1.2	-4.2	-3.6	3.4	-0.4	-1.1	8.2	3.4	1.5	11.8	6.1	3.1	13.6	7.2	3.8
35	-17.3	-16.5	-11.0	-11.6	-12.1	-8.4	-6.0	-8.2	-6.4	-1.0	-4.6	-4.1	4.3	-0.4	-1.2	9.5	4.1	1.7	13.7	7.3	3.6	15.7	8.4	4.4
40	-18.4	-18.2	-12.5	-12.3	-13.3	-9.5	-6.2	-9.0	-7.1	-0.6	-4.8	-4.5	5.2	-0.2	-1.3	11.0	4.8	2.0	15.6	8.2	4.1	17.8	9.5	5.0
45	-19.2	-19.7	-13.9	-12.7	-14.3	-10.5	-6.1	-9.6	-7.8	-0.1	-5.0	-4.9	6.2	0.1	-1.3	12.5	5.5	2.3	17.5	9.3	4.7	20.0	10.6	5.5
50	-19.6	-20.9	-15.1	-12.8	-15.1	-11.4	-5.8	-10.2	-8.4	0.5	-5.1	-5.2	7.2	0.4	-1.3	14.0	6.2	2.6	19.5	10.3	5.3	22.1	11.8	6.1
55	-19.6	-21.8	-16.3	-12.6	-15.8	-12.2	-5.3	-10.5	-8.9	1.4	-5.1	-5.5	8.4	0.7	-1.3	15.7	6.9	2.9	21.5	11.3	5.8	24.3	13.0	6.7
60	-19.5	-22.6	-17.3	-12.3	-16.2	-13.0	-4.7	-10.7	-9.4	2.3	-5.1	-5.7	9.6	1.2	-1.3	17.3	7.7	3.4	23.4	12.3	6.3	26.4	14.2	7.3
65	-19.1	-23.0	-18.2	-11.8	-16.5	-13.6	-3.9	-10.7	-9.9	3.3	-4.9	-5.8	10.9	1.7	-1.1	19.0	8.6	3.7	25.4	13.4	6.9	28.5	15.4	7.9
70	-18.3	-23.2	-18.9	-10.9	-16.5	-14.1	-2.7	-10.5	-10.1	4.7	-4.4	-5.9	12.5	2.4	-0.9	21.0	9.6	4.2	27.7	14.6	7.4	31.0	16.7	8.6

Heating - Relative Energy Efficiency (%)

Orientation

S-| = Single glazing , D-|| = Double glazing , T=||| = Triple glazing

WWR (%)	N			NNE			NE			ENE			E			ESE			SE			SSE		
	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	2.1	1.2	0.6	1.5	0.6	0.3	0.0	-0.4	-0.4	-1.7	-1.4	-1.3	-3.3	-3.1	-2.3	-4.3	-4.0	-2.7	-4.6	-4.0	-2.7	-4.2	-3.4	-2.2
10	4.4	2.4	1.3	2.9	1.3	0.7	0.5	-0.5	-0.6	-2.6	-3.0	-2.2	-5.5	-5.5	-4.0	-7.6	-7.2	-4.9	-8.5	-7.6	-5.0	-7.9	-6.5	-4.2
15	6.6	3.6	2.0	4.5	2.1	1.1	1.4	-0.4	-0.7	-2.9	-3.9	-3.0	-7.1	-7.5	-5.6	-10.1	-10.0	-7.1	-11.8	-10.8	-7.3	-11.3	-9.5	-6.1
20	8.6	4.8	2.6	6.2	2.9	1.4	2.5	-0.1	-0.7	-2.8	-4.5	-3.8	-8.0	-9.1	-7.0	-12.1	-12.5	-9.1	-14.5	-13.8	-9.5	-14.3	-12.4	-8.0
25	11.0	6.0	3.2	8.3	3.9	1.9	3.9	0.3	-0.7	-1.9	-4.7	-4.2	-8.0	-10.1	-8.2	-13.0	-14.3	-10.9	-16.4	-16.3	-11.6	-16.8	-15.0	-9.9
30	13.2	7.2	3.9	10.2	4.8	2.3	5.4	0.8	-0.5	-0.8	-4.7	-4.7	-7.7	-10.8	-9.2	-13.5	-15.8	-12.5	-17.9	-18.5	-13.4	-18.9	-17.4	-11.7
35	15.3	8.3	4.5	12.1	5.8	2.7	7.0	1.5	-0.4	0.4	-4.5	-5.0	-7.1	-11.2	-10.1	-13.8	-17.0	-13.8	-19.0	-20.5	-15.2	-20.5	-19.7	-13.5
40	17.4	9.4	5.0	14.0	6.8	3.1	8.8	2.2	-0.3	1.8	-4.1	-5.2	-6.3	-11.4	-10.8	-13.6	-17.9	-15.0	-19.6	-22.1	-16.9	-21.6	-21.6	-15.1
45	19.5	10.6	5.6	16.0	7.8	3.6	10.8	3.0	0.0	3.5	-3.4	-5.3	-5.2	-11.3	-11.4	-13.1	-18.5	-16.1	-19.8	-23.4	-18.4	-22.3	-23.2	-16.7
50	21.6	11.7	6.2	18.0	8.8	4.0	12.8	4.0	0.2	5.3	-2.7	-5.3	-3.9	-11.0	-11.8	-12.4	-18.7	-17.0	-19.6	-24.3	-19.7	-22.6	-24.5	-18.1
55	23.8	12.9	6.8	20.1	9.9	4.5	15.0	5.0	0.5	7.1	-1.7	-5.3	-2.5	-10.6	-12.0	-11.3	-18.7	-17.9	-18.9	-24.9	-20.9	-22.4	-25.5	-19.4
60	25.9	14.1	7.4	20.5	11.0	5.1	17.1	6.2	0.9	9.1	-0.8	-5.1	-0.9	-10.0	-12.2	-10.1	-18.7	-18.5	-18.0	-25.3	-21.9	-22.0	-26.2	-20.6
65	28.0	15.3	8.0	24.3	12.1	5.6	19.4	7.3	1.3	11.1	0.3	-4.8	0.7	-9.3	-12.2	-8.8	-18.3	-18.9	-16.9	-25.5	-22.8	-21.3	-26.7	-21.6
70	30.5	16.6	8.6	26.8	13.4	6.2	22.0	8.8	1.9	13.5	1.5	-4.3	2.8	-8.7	-12.0	-6.9	-17.7	-19.2	-15.3	-25.3	-23.5	-20.2	-26.9	-22.5

WWR (%)	S			SSW			SW			WSW			W			WNW			NW			NNW		
	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	-3.3	-2.8	-1.7	-2.4	-2.1	-1.3	-1.5	-1.6	-1.1	-0.7	-1.0	-0.8	0.1	-0.4	-0.3	1.1	0.4	0.2	1.9	0.9	0.5	2.2	1.2	0.6
10	-6.2	-5.3	-3.3	-4.5	-4.1	-2.7	-2.7	-3.0	-2.1	-1.1	-1.8	-1.4	0.6	-0.5	-0.5	2.4	1.0	0.4	3.8	2.0	1.0	4.5	2.4	1.3
15	-8.9	-7.7	-4.9	-6.3	-5.8	-3.9	-3.7	-4.3	-3.0	-1.2	-2.4	-1.9	1.4	-0.5	-0.6	4.1	1.7	0.7	5.9	3.0	1.6	6.9	3.6	1.9
20	-11.6	-10.1	-6.4	-8.0	-7.6	-5.0	-4.3	-5.4	-3.9	-1.1	-3.1	-2.5	2.2	-0.4	-0.7	5.6	2.3	1.0	7.9	4.0	2.0	9.0	4.8	2.6
25	-13.8	-12.4	-7.9	-9.4	-9.1	-6.1	-4.7	-6.3	-4.7	-0.7	-3.4	-2.9	3.3	-0.1	-0.8	7.3	3.2	1.4	10.2	5.3	2.6	11.5	6.0	3.2
30	-15.7	-14.5	-9.5	-10.4	-10.7	-7.2	-5.0	-7.1	-5.5	-0.3	-3.6	-3.4	4.4	0.2	-0.8	9.1	4.0	1.7	12.4	6.5	3.2	13.8	7.3	3.8
35	-17.2	-16.5	-11.0	-11.3	-12.1	-8.4	-5.1	-7.8	-6.2	0.2	-3.8	-3.7	5.6	0.5	-0.9	10.6	4.8	2.0	14.4	7.7	3.8	15.9	8.5	4.4
40	-18.3	-18.2	-12.5	-11.8	-13.2	-9.4	-5.1	-8.4	-6.9	0.9	-3.9	-4.1	6.8	0.9	-0.8	12.4	5.7	2.4	16.5	8.8	4.3	18.2	9.6	5.0
45	-19.0	-19.6	-13.9	-12.2	-14.2	-10.4	-4.9	-8.9	-7.6	1.7	-3.9	-4.3	8.1	1.3	-0.7	14.1	6.5	2.8	18.5	9.9	5.0	20.4	10.8	5.6
50	-19.3	-20.9	-15.1	-12.1	-14.9	-11.3	-4.3	-9.4	-8.1	2.6	-3.8	-4.6	9.3	1.9	-0.6	15.9	7.4	3.2	20.7	11.0	5.7	22.6	12.0	6.2
55	-19.2	-21.7	-16.3	-11.8	-15.6	-12.2	-3.6	-9.5	-8.5	3.7	-3.6	-4.8	10.8	2.4	-0.5	17.7	8.3	3.7	22.8	12.2	6.2	24.9	13.3	6.8
60	-18.9	-22.5	-17.3	-11.4	-16.0	-12.9	-2.7	-9.6	-9.0	4.9	-3.4	-4.8	12.3	3.1	-0.3	19.6	9.3	4.2	25.0	13.3	6.8	27.0	14.5	7.4
65	-18.4	-22.9	-18.2	-10.8	-16.2	-13.5	-1.7	-9.5	-9.4	6.1	-3.0	-4.9	13.9	3.8	-0.1	21.5	10.3	4.6	27.1	14.5	7.4	29.3	15.7	8.1
70	-17.5	-23.1	-18.9	-9.7	-16.1	-14.0	-0.3	-9.1	-9.6	7.8	-2.3	-4.9	15.7	4.7	0.3	23.8	11.6	5.2	29.6	15.8	8.0	31.8	17.1	8.7

Total - Relative Energy Efficiency (%)

Figure 6. Energy efficiency heatmaps by orientation, WWR, and glazing type in Bamian (Dsb).

In contrast, the heating efficiency data (middle table) demonstrate significant reductions in heating demand associated with increasing WWR, particularly for south-facing orientations spanning from east-northeast (ENE) to west-southwest (WSW), whereas other orientations experience an increase in energy consumption. This effect is further enhanced when employing high-performance glazing systems, such as double or triple glazing, which enable beneficial passive solar heat gains while reducing heat losses. Specifically, at WWR values between 50% and 70%, double-glazed windows oriented toward south (S), south-southeast (SSE), and south-southwest (SSW) achieve heating energy savings of approximately 28%, underscoring the effectiveness of passive solar design strategies in heating-dominated climates like that of Bamian. Furthermore, the results reveal that for smaller window sizes, single-glazed windows outperform double- and triple-glazed windows in heating efficiency. However, as window size increases, double- and triple-glazed windows exhibit superior performance relative to single glazing, particularly when optimally oriented between ENE and WSW. This is primarily due to the greater insulation benefits of multi-glazing systems becoming increasingly important in larger windows, offsetting heat losses more effectively while still allowing substantial passive solar gains.

The bottom table in **Figure 6** illustrates total annual energy efficiency, combining both heating and cooling performance to provide a holistic assessment of energy demand. Given Bamian's heating-dominated climate, total energy consumption is primarily influenced by heating loads. The analysis shows that increasing the WWR on northern orientations (from W to ENE) results in higher overall energy use due to limited solar gain and increased heat loss through larger window areas. Conversely, south-facing façades (ENE to W), particularly those oriented toward SSE, exhibit significant reductions in total energy demand when paired with higher WWRs and high-performance glazing. Notably, the greatest total energy savings—22.5%, 26.9%, and 22.6%—occur with WWRs of 70%, 70%, and 45% for triple-, double-, and single-glazed windows, respectively, on SSE-oriented façades.

3.2. Arid, Stepped, and Cold (BSk) Climate—Ghazni and Mazar-E-Sharif

Figure 7 and **Figure 8** illustrate the relative energy efficiency of residential buildings in Ghazni (**Figure 7**) and Mazar-e-Sharif (**Figure 8**), both located in Afghanistan's cold semi-arid (BSk) climate zone. While Ghazni is predominantly heating-oriented, Mazar-e-Sharif experiences higher cooling demands.

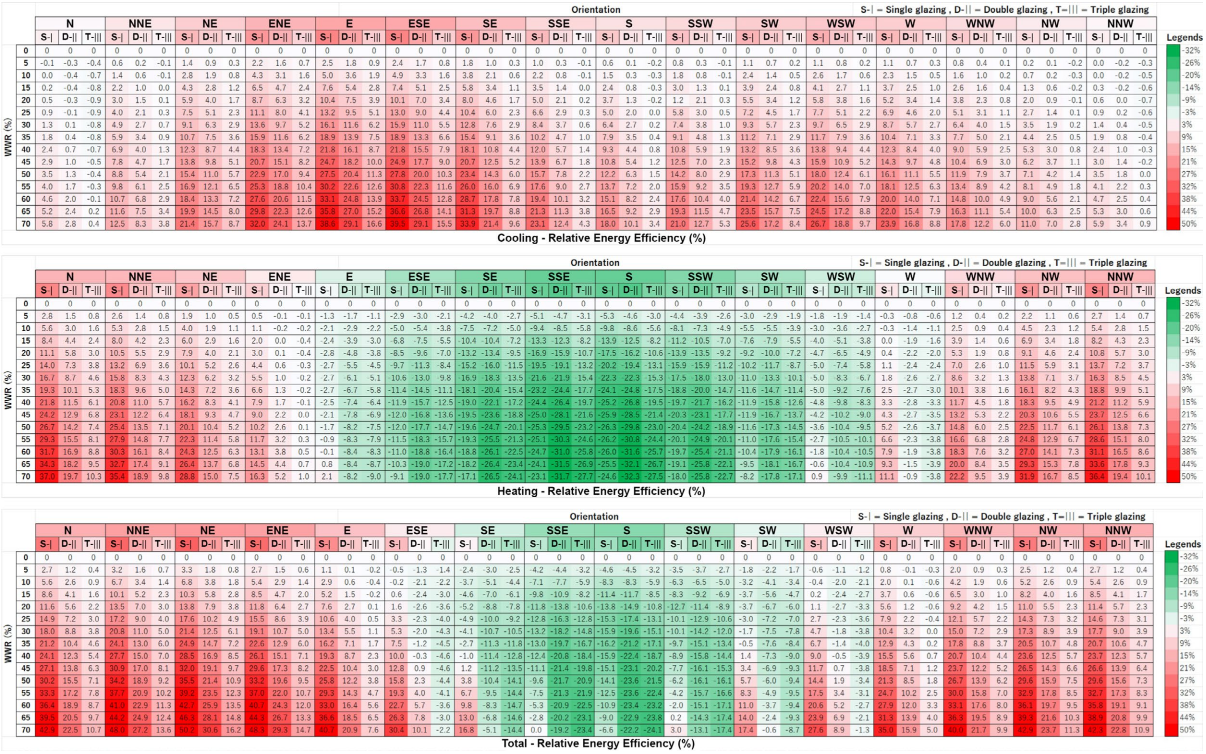
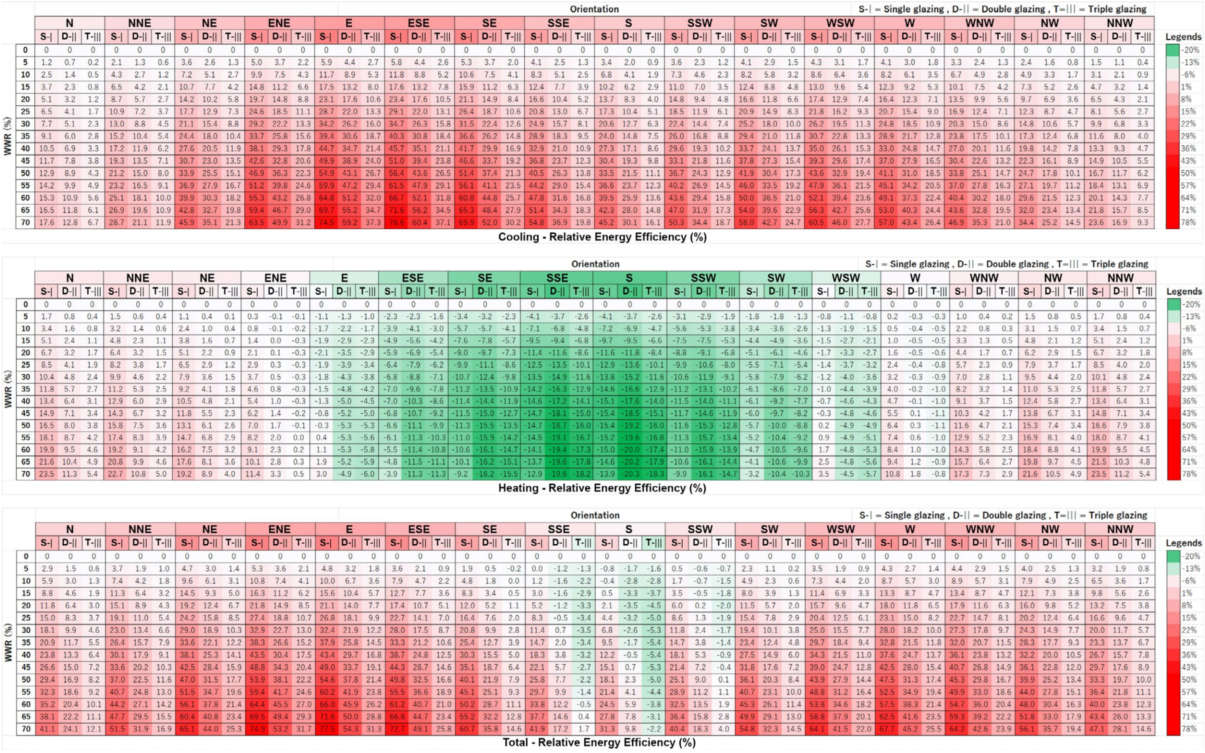


Figure 7. Energy efficiency heatmaps by orientation, WWR, and glazing type in Ghazni (BSk).



Orientation

S-| = Single glazing , D-|| = Double glazing , T=||| = Triple glazing

WWR (%)	N			NNE			NE			ENE			E			ESE			SE			SSE		
	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	1.2	0.7	0.2	2.1	1.3	0.6	3.6	2.6	1.3	5.0	3.7	2.2	5.9	4.4	2.7	5.8	4.4	2.6	5.3	3.7	2.0	4.1	2.5	1.3
10	2.5	1.4	0.5	4.3	2.7	1.2	7.2	5.1	2.7	9.9	7.5	4.3	11.7	8.9	5.3	11.8	8.8	5.2	10.6	7.5	4.1	8.3	5.1	2.5
15	3.7	2.3	0.8	6.5	4.2	2.1	10.7	7.7	4.2	14.8	11.2	6.6	17.5	13.2	8.0	17.6	13.2	7.8	15.9	11.2	6.3	12.4	7.7	3.9
20	5.1	3.2	1.2	8.7	5.7	2.7	14.2	10.2	5.8	19.7	14.8	8.8	23.1	17.6	10.6	23.4	17.6	10.5	21.1	14.9	8.4	16.6	10.4	5.2
25	6.5	4.1	1.7	10.9	7.2	3.7	17.7	12.9	7.3	24.6	18.5	11.1	28.7	22.0	13.3	29.1	22.0	13.1	26.4	18.7	10.6	20.8	13.0	6.7
30	7.7	5.1	2.3	13.0	8.8	4.5	21.1	15.4	8.8	29.2	22.2	13.3	34.2	26.2	16.0	34.7	26.3	15.8	31.5	22.4	12.6	24.9	15.7	8.1
35	9.1	6.0	2.8	15.2	10.4	5.4	24.4	18.0	10.4	33.7	25.8	15.6	39.4	30.6	18.7	40.3	30.8	18.4	36.6	26.2	14.8	28.9	18.3	9.5
40	10.5	6.9	3.3	17.2	11.9	6.2	27.6	20.5	11.9	38.1	29.3	17.8	44.7	34.7	21.4	45.7	35.1	21.1	41.7	29.9	16.9	32.9	21.0	10.9
45	11.7	7.8	3.8	19.3	13.5	7.1	30.7	23.0	13.5	42.6	32.8	20.6	49.9	38.9	24.0	51.0	39.4	23.8	46.6	33.7	19.2	36.8	23.7	12.3
50	12.9	8.9	4.3	21.2	15.0	8.0	33.9	25.5	15.1	46.9	36.3	22.3	54.9	43.1	26.7	56.4	43.6	26.5	51.4	37.4	21.3	40.5	26.3	13.8
55	14.2	9.9	4.9	23.2	16.5	9.1	36.9	27.9	16.7	51.2	39.8	24.6	59.9	47.2	29.4	61.5	47.9	29.1	56.1	41.1	23.5	44.2	29.0	15.4
60	15.3	10.9	5.6	25.1	18.1	10.0	39.9	30.3	18.2	55.3	43.2	26.8	64.8	51.2	32.0	66.7	52.1	31.8	60.8	44.8	25.7	47.8	31.6	16.8
65	16.5	11.8	6.1	26.9	19.6	10.9	42.8	32.7	19.8	59.4	46.7	29.0	69.7	55.2	34.7	71.6	56.2	34.5	65.3	48.4	27.9	51.4	34.3	18.3
70	17.6	12.8	6.7	28.7	21.1	11.9	45.9	35.1	21.3	63.5	49.9	31.2	74.5	59.2	37.3	76.6	60.4	37.1	69.9	52.0	30.2	54.8	36.9	19.8

WWR (%)	S			SSW			SW			WSW			W			WNW			NW			NNW		
	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	3.4	2.0	0.9	3.6	2.3	1.2	4.1	2.9	1.5	4.3	3.1	1.7	4.1	3.0	1.8	3.3	2.4	1.3	2.4	1.6	0.8	1.5	1.1	0.4
10	6.8	4.1	1.9	7.3	4.6	2.3	8.2	5.8	3.2	8.6	6.4	3.6	8.2	6.1	3.5	6.7	4.9	2.8	4.9	3.3	1.7	3.1	2.1	0.9
15	10.2	6.2	2.9	11.0	7.0	3.5	12.4	8.8	4.8	13.0	9.6	5.4	12.3	9.2	5.3	10.1	7.5	4.2	7.3	5.2	2.6	4.7	3.2	1.4
20	13.7	8.3	4.0	14.8	9.4	4.8	16.6	11.8	6.6	17.4	12.9	7.4	16.4	12.3	7.1	13.5	9.9	5.6	9.7	6.9	3.6	6.5	4.3	2.1
25	17.3	10.4	5.1	18.5	11.9	6.1	20.9	14.9	8.3	21.8	16.2	9.3	20.7	15.4	9.0	16.9	12.4	7.1	12.3	8.7	4.7	8.1	5.6	2.7
30	20.6	12.7	6.3	22.4	14.4	7.4	25.2	18.0	10.0	26.2	19.5	11.3	24.8	18.5	10.9	20.3	15.0	8.6	14.8	10.6	5.7	9.9	6.8	3.3
35	24.0	14.8	7.5	26.0	16.8	8.8	29.4	21.0	11.8	30.7	22.8	13.3	28.9	21.7	12.8	23.8	17.5	10.1	17.3	12.4	6.8	11.6	8.0	4.0
40	27.3	17.1	8.6	29.6	19.3	10.2	33.7	24.1	13.7	35.0	26.1	15.3	33.0	24.8	14.7	27.0	20.1	11.6	19.8	14.2	7.8	13.3	9.3	4.7
45	30.4	19.3	9.8	33.1	21.8	11.6	37.8	27.3	15.4	39.3	29.6	17.4	37.0	27.9	16.5	30.4	22.6	13.2	22.3	16.1	8.9	14.9	10.5	5.5
50	33.5	21.5	11.1	36.7	24.3	12.9	41.9	30.4	17.3	43.6	32.9	19.4	41.1	31.0	18.5	33.8	25.1	14.7	24.7	17.8	10.1	16.7	11.7	6.2
55	36.6	23.7	12.3	40.2	26.9	14.5	46.0	33.5	19.2	47.9	36.1	21.5	45.1	34.2	20.5	37.0	27.8	16.3	27.1	19.7	11.2	18.4	13.1	6.9
60	39.5	25.9	13.6	43.6	29.4	15.8	50.0	36.5	21.0	52.1	39.4	23.6	49.1	37.3	22.4	40.4	30.2	18.0	29.6	21.5	12.3	20.1	14.3	7.7
65	42.3	28.0	14.8	47.0	31.9	17.3	54.0	39.6	22.9	56.3	42.7	25.6	53.0	40.3	24.4	43.6	32.8	19.5	32.0	23.4	13.4	21.8	15.7	8.5
70	45.2	30.1	16.1	50.3	34.4	18.7	58.0	42.7	24.7	60.5	46.0	27.7	57.0	43.4	26.4	46.9	35.3	21.0	34.4	25.2	14.5	23.6	16.9	9.3

Cooling - Relative Energy Efficiency (%)

Legends

-20%
-13%
-6%
1%
8%
15%
22%
29%
36%
43%
50%
57%
64%
71%
78%

Orientation

S-| = Single glazing , D-|| = Double glazing , T=||| = Triple glazing

WWR (%)	N			NNE			NE			ENE			E			ESE			SE			SSE		
	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	1.7	0.8	0.4	1.5	0.6	0.4	1.1	0.4	0.1	0.3	-0.1	-0.1	-1.1	-1.3	-1.0	-2.3	-2.3	-1.6	-3.4	-3.2	-2.3	-4.1	-3.7	-2.6
10	3.4	1.6	0.8	3.2	1.4	0.6	2.4	1.0	0.4	0.8	-0.1	-0.2	-1.7	-2.2	-1.7	-3.9	-4.1	-3.0	-5.7	-5.7	-4.1	-7.1	-6.8	-4.8
15	5.1	2.4	1.1	4.8	2.3	1.1	3.8	1.6	0.7	1.4	0.0	-0.3	-1.9	-2.9	-2.3	-4.9	-5.6	-4.2	-7.6	-7.8	-5.7	-9.5	-9.4	-6.8
20	6.7	3.2	1.7	6.4	3.2	1.5	5.1	2.2	0.9	2.1	0.1	-0.3	-2.1	-3.5	-2.9	-5.9	-6.9	-5.4	-9.0	-9.7	-7.3	-11.4	-11.6	-8.6
25	8.5	4.1	1.9	8.2	3.8	1.7	6.5	2.9	1.2	2.9	0.3	-0.3	-1.9	-3.9	-3.4	-6.4	-7.9	-6.2	-9.9	-11.1	-8.6	-12.5	-13.5	-10.1
30	10.4	4.8	2.4	9.9	4.6	2.2	7.9	3.6	1.5	3.7	0.5	-0.3	-1.8	-4.3	-3.8	-6.8	-8.8	-7.1	-10.7	-12.4	-9.8	-13.5	-14.9	-11.6
35	11.8	5.7	2.7	11.2	5.3	2.5	9.2	4.1	1.8	4.6	0.8	-0.3	-1.5	-4.8	-4.2	-7.0	-9.6	-7.8	-11.2	-13.5	-10.9	-14.2	-16.3	-12.9
40	13.4	6.4	3.1	12.9	6.0	2.9	10.5	4.8	2.1	5.4	1.0	-0.3	-1.3	-5.0	-4.5	-7.0	-10.3	-8.6	-11.4	-14.4	-11.9	-14.6	-17.2	-14.1
45	14.9	7.1	3.4	14.3	6.7	3.2	11.8	5.5	2.3	6.2	1.4	-0.2	-0.8	-5.2	-5.0	-6.8	-10.7	-9.2	-11.5	-15.0	-12.7	-14.7	-18.1	-15.0
50	16.5	8.0	3.8	15.8	7.5	3.6	13.1	6.1	2.6	7.0	1.7	-0.1	-0.3	-5.3	-5.3	-6.6	-11.1	-9.9	-11.3	-15.5	-13.5	-14.7	-18.7	-16.0
55	18.1	8.7	4.2	17.4	8.3	3.9	14.7	6.8	2.9	8.2	2.0	0.0	0.4	-5.3	-5.6	-6.1	-11.3	-10.3	-11.0	-15.9	-14.2	-14.5	-19.1	-16.7
60	19.9	9.5	4.6	19.2	9.1	4.2	16.2	7.5	3.2	9.1	2.3	0.2	1.1	-5.3	-5.8	-5.5	-11.4	-10.8	-10.6	-16.1	-14.7	-14.1	-19.4	-17.3
65	21.6	10.4	4.9	20.8	9.9	4.6	17.6	8.1	3.6	10.1	2.8	0.3	1.9	-5.2	-5.9	-4.8	-11.5	-11.1	-10.1	-16.2	-15.1	-13.7	-19.6	-17.8
70	23.5	11.3	5.4	22.7	10.8	5.0	19.2	8.9	4.0	11.4	3.3	0.5	3.0	-4.9	-6.0	-3.9	-11.3	-11.3	-9.2	-16.2	-15.5	-12.9	-19.6	-18.2

WWR (%)	S			SSW			SW			WSW			W			WNW			NW			NNW		
	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	-4.1	-3.7	-2.6	-3.1	-2.9	-1.9	-1.8	-1.8	-1.3	-0.8	-1.1	-0.8	0.2	-0.3	-0.3	1.0	0.4	0.2	1.5	0.8	0.5	1.7	0.8	0.4
10	-7.2	-6.9	-4.7	-5.6	-5.3	-3.8	-3.4	-3.6	-2.6	-1.3	-1.9	-1.5	0.5	-0.4	-0.5	2.2	0.8	0.3	3.1	1.5	0.7	3.4	1.5	0.7
15	-9.7	-9.5	-6.6	-7.5	-7.5	-5.3	-4.4	-4.9	-3.6	-1.5	-2.7	-2.1	1.0	-0.5	-0.5	3.3	1.3	0.5	4.8	2.1	1.2	5.1	2.4	1.2
20	-11.6	-11.8	-8.4	-8.8	-9.1	-6.8	-5.1	-6.1	-4.6	-1.7	-3.3	-2.7	1.6	-0.5	-0.6	4.4	1.7	0.7	6.2	2.9	1.5	6.7	3.2	1.8
25	-12.9	-13.6	-10.1	-9.9	-10.6	-8.0	-5.5	-7.1	-5.4	-1.4	-3.7	-3.2	2.4	-0.4	-0.8	5.7	2.3	0.9	7.9	3.7	1.7	8.5	4.0	2.0
30	-13.8	-15.2	-11.6	-10.6	-11.9	-9.1	-5.8	-7.9	-6.2	-1.2	-4.0	-3.6	3.2	-0.3	-0.9	7.0	2.8	1.1	9.5	4.4	2.0	10.1	4.8	2.4
35	-14.6	-16.6	-12.9	-11.2	-13.1	-10.2	-6.1	-8.6	-7.0	-1.0	-4.4	-3.9	4.0	-0.2	-1.0	8.2	3.2	1.4	11.0	5.3	2.5	11.8	5.7	2.7
40	-15.1	-17.6	-14.0	-11.5	-14.0	-11.1	-6.1	-9.2	-7.7	-0.7	-4.6	-4.3	4.7	-0.1	-1.0	9.1	3.7	1.5	12.4	5.8	2.7	13.4	6.4	3.1
45	-15.4	-18.5	-15.1	-11.7	-14.6	-11.9	-6.0	-9.7	-8.2	-0.3	-4.8	-4.6	5.5	0.1	-1.1	10.3	4.2	1.7	13.8	6.7	3.1	14.8	7.1	3.4
50	-15.4	-19.2	-16.0	-11.6	-15.3	-12.8	-5.7	-10.0	-8.8	0.2	-4.9	-4.9	6.4	0.3	-1.1	11.6	4.7	2.1	15.3	7.4	3.4	16.6	7.9	3.8
55	-15.2	-19.6	-16.8	-11.3	-15.7	-13.4	-5.2	-10.4	-9.2	0.9	-4.9	-5.1	7.4	0.6	-1.0	12.9	5.2	2.3	16.9	8.1	4.0	18.0	8.7	4.1
60	-15.0	-20.0	-17.4	-11.0	-15.9	-13.9	-4.7	-10.5	-9.6	1.7	-4.8	-5.3	8.4	1.0	-1.0	14.3	5.8	2.5	18.4	8.8	4.1	19.9	9.5	4.5
65	-14.6	-20.2	-17.9	-10.6	-16.1	-14.4	-4.1	-10.6	-9.9	2.5	-4.8	-5.6	9.4	1.2	-0.9	15.7	6.4	2.7	19.8	9.7	4.5	21.5	10.3	4.8
70	-13.9	-20.3	-18.3	-9.9	-16.1	-14.7	-3.2	-10.4	-10.3	3.5	-4.5	-5.7	10.8	1.8	-0.8	17.3	7.3	2.9	21.6	10.5	4.9	23.5	11.2	5.4

Heating - Relative Energy Efficiency (%)

Legends

-20%
-13%
-6%
1%
8%
15%
22%
29%
36%
43%
50%
57%
64%
71%
78%

Orientation

S-| = Single glazing , D-|| = Double glazing , T=||| = Triple glazing

WWR (%)	N			NNE			NE			ENE			E			ESE			SE			SSE		
	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	2.9	1.5	0.6	3.7	1.9	1.0	4.7	3.0	1.4	5.3	3.6	2.1	4.8	3.2	1.8	3.6	2.1	0.9	1.9	0.5	-0.2	0.0	-1.2	-1.3
10	5.9	3.0	1.3	7.4	4.2	1.8	9.6	6.1	3.1	10.8	7.4	4.1	10.0	6.7	3.6	7.9	4.7	2.2	4.8	1.8	0.0	1.2	-1.6	-2.2
15	8.8	4.6	1.9	11.3	6.4	3.2	14.5	9.3	5.0	16.3	11.2	6.2	15.6	10.4	5.7	12.7	7.7	3.6	8.3	3.4	0.5	3.0	-1.6	-2.9
20	11.8	6.4	3.0	15.1	8.9	4.3	19.2	12.4	6.7	21.8	14.9	8.5	21.1	14.0	7.7	17.4	10.7	5.1	12.0	5.2	1.1	5.2	-1.2	-3.3
25	15.0	8.3	3.7	19.1	11.0	5.4	24.2	15.8	8.5	27.4	18.8	10.7	26.8	18.1	9.9	22.7	14.1	7.0	16.4	7.6	2.0	8.3	-0.5	-3.4
30	18.1	9.9	4.6	23.0	13.4	6.6	29.0	18.9	10.3	32.9	22.7	13.0	32.4	21.9	12.2	28.0	17.5	8.7	20.8	9.9	2.8	11.4	0.7	-3.5
35	20.9	11.7	5.5	26.4	15.7	7.9	33.6	22.1	12.2	38.3	26.6	15.2	37.9	25.8	14.5	33.3	21.2	10.6	25.4	12.7	3.9	14.7	2.0	-3.4
40	23.8	13.3	6.4	30.1	17.9	9.1	38.1	25.3	14.1	43.5	30.4	17.5	43.4	29.7	16.8	38.7	24.8	12.5	30.3	15.5	5.0	18.3	3.8	-3.2
45	26.6	15.0	7.2	33.6	20.2	10.3	42.5	28.4	15.9	48.8	34.3	20.4	49.0	33.7	19.1	44.3	28.7	14.6	35.1	18.7	6.4	22.1	5.7	-2.7
50	29.4	16.9	8.2	37.0	22.5	11.6	47.0	31.5	17.7	53.9	38.1	22.2	54.6	37.8	21.4	49.8	32.5	16.6	40.1	21.9	7.9	25.8	7.7	-2.2
55	32.3	18.6	9.2	40.7	24.8	13.0	51.5	34.7	19.6	59.4	41.7	24.6	60.2	41.9	23.8	55.5	36.6	18.9	45.1	25.1	9.3	29.7	9.9	-1.4
60	35.2	20.4	10.1	44.2	27.1	14.2	56.1	37.8	21.4	64.4	45.5	27.0	66.0	45.9	26.2	61.2	40.7	21.0	50.2	28.7	11.1	33.8	12.2	-0.5
65	38.1	22.2	11.1	47.7	29.5	15.5	60.4	40.8	23.4	69.5	49.4	29.3	71.6	50.0	28.8	66.8	44.7	23.4	55.2	32.2	12.8	37.7	14.6	0.4
70	41.1	24.1	12.1	51.5	31.9	16.9	65.1	44.0	25.3	74.9	53.2	31.7	77.5	54.3	31.3	72.7	49.1	25.8	60.7	35.8	14.6	41.9	17.2	1.7

WWR (%)	S			SSW			SW			WSW			W			WNW			NW			NNW		
	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	-0.8	-1.7	-1.6	0.5	-0.6	-0.7	2.3	1.1	0.2	3.5	1.9	0.9	4.3	2.7	1.4	4.4	2.9	1.5	4.0	2.5	1.3	3.2	1.9	0.8
10	-0.4	-2.8	-2.8	1.7	-0.7	-1.5	4.9	2.3	0.6	7.3	4.4	2.0	8.7	5.7	3.0	8.9	5.7	3.1	7.9	4.9	2.5	6.5	3.6	1.7
15	0.5	-3.3	-3.7	3.5	-0.5	-1.8	8.0	3.9	1.3	11.4	6.9	3.3	13.3	8.7	4.7	13.4	8.7	4.7	12.1	7.3	3.8	9.8	5.6	2.6
20	2.1	-3.5	-4.5	6.0	0.2	-2.0	11.5	5.7	2.0	15.7	9.6	4.7	18.0	11.8	6.5	17.9	11.6	6.3	16.0	9.8	5.2	13.2	7.5	3.8
25	4.4	-3.2	-5.0	8.6	1.3	-1.9	15.4	7.8	2.9	20.4	12.5	6.1	23.1	15.0	8.2	22.7	14.7	8.1	20.2	12.4	6.4	16.6	9.6	4.7
30	6.8	-2.6	-5.3	11.8	2.4	-1.7	19.4	10.1	3.8	25.0	15.5	7.7	28.0	18.2	10.0	27.3	17.8	9.7	24.3	14.9	7.7	20.0	11.7	5.7
35	9.5	-1.7	-5.4	14.7	3.8	-1.4	23.4	12.4	4.8	29.7	18.4	9.4	32.8	21.5	11.8	32.0	20.7	11.5	28.3	17.7	9.3	23.3	13.7	6.7
40	12.2	-0.5	-5.4	18.1	5.3	-0.9	27.5	14.9	6.0	34.3	21.5	11.0	37.6	24.7	13.7	36.1	23.8	13.2	32.2	20.0	10.5	26.7	15.7	7.8
45	15.1	0.7	-5.3	21.4	7.2	-0.4	31.8	17.6	7.2	39.0	24.7	12.8	42.5	28.0	15.4	40.7	26.8	14.9	36.1	22.8	12.0	29.7	17.6	8.9
50	18.1	2.3	-5.0	25.1	9.0	0.1	36.1	20.3	8.4	43.9	27.9	14.4	47.5	31.3	17.4	45.3	29.8	16.7	39.9	25.2	13.4	33.3	19.7	10.0
55	21.4	4.1	-4.4	28.9	11.2	1.1	40.7	23.1	10.0	48.8	31.2	16.4	52.5	34.9	19.4	49.9	33.0	18.6	44.0	27.8	15.1	36.4	21.8	11.1
60	24.5	5.9	-3.8	32.5	13.5	1.9	45.3	26.1	11.4	53.8	34.6	18.2	57.5	38.3	21.4	54.7	36.0	20.4	48.0	30.4	16.3	40.0	23.8	12.3
65	27.8	7.8	-3.1	36.4	15.8	2.8	49.9	29.1	13.0	58.8	37.9	20.1	62.5	41.6	23.5	59.3	39.2	22.2	51.8	33.0	17.9	43.4	26.0	13.3
70	31.3	9.8	-2.2	40.4	18.3	4.0	54.8	32.3	14.5	64.1	41.5	22.0	67.7	45.2	25.5	64.2	42.6	23.9	56.1	35.7	19.4	47.1	28.1	14.6

Total - Relative Energy Efficiency (%)

Legends

-20%
-13%
-6%
1%
8%
15%
22%
29%
36%
43%
50%
57%
64%
71%
78%

Figure 8. Energy efficiency heatmaps by orientation, WWR, and glazing type in Mazar-E-Sharif (BSk).

The top tables in each figure show cooling energy efficiency. Across both cities, increasing WWR leads to a decline in cooling performance, particularly for façades facing east, west, and their adjacent orientations (ENE, ESE, WSW, WNW), which receive intense solar radiation during morning and afternoon hours. Single-glazed windows consistently perform the worst due to poor solar control. Although double and triple glazing mitigate solar heat gain to some extent, cooling loads continue to increase with larger window areas regardless of glazing type. This effect is more pronounced in Mazar-e-Sharif, where higher ambient temperatures and longer cooling periods result in greater cooling energy penalties.

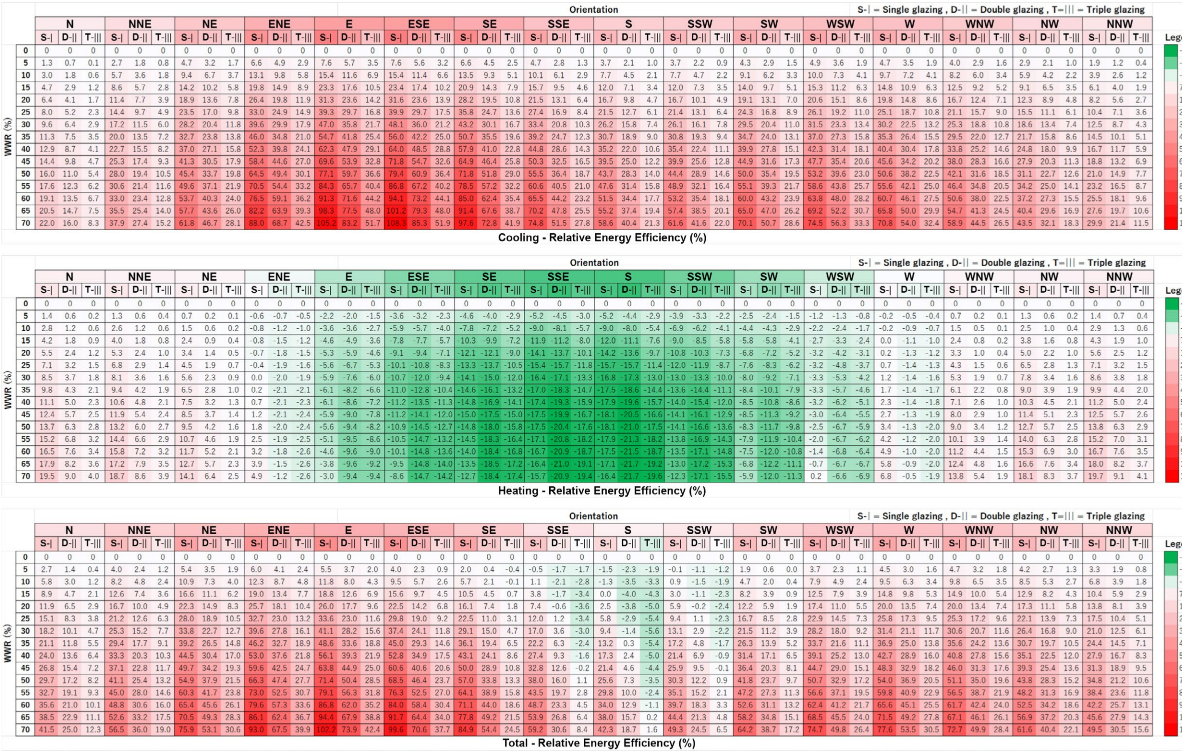
The middle tables present heating energy efficiency. The results indicate a significant improvement in performance with increasing WWR on south-facing façades—E to WSW—particularly when high-performance glazing is applied. Double- and triple-glazed windows with WWRs between 50% and 70% achieve substantial reductions in heating loads, reaching up to 33% in Ghazni and 21% in Mazar-e-Sharif. In contrast, orientations outside this south-facing range generally result in higher heating energy demand as WWR increases. These findings underscore the potential of passive solar heating strategies in heating-oriented environments like Ghazni.

The bottom tables display total annual energy efficiency, combining both cooling and heating dynamics. Results reveal that east- and west-facing façades with large WWRs are generally inefficient due to high cooling demands that outweigh any winter heating benefits. In contrast, south-facing façades with moderate-to-high WWRs and high-performance glazing achieve the best overall energy savings. Notably, Ghazni exhibits more significant total energy savings than Mazar-e-Sharif due to its dominant heating requirements. In Ghazni, maximum savings of 24.1%, 23.6%, and 16.2% are achieved with triple-, double-, and single-glazed windows at WWRs of 70%, 50% - 55%, and 35%, respectively, on south-facing façades. Mazar-e-Sharif shows lower overall potential, with maximum savings of 5.4%, 3.5%, and 0.8% at WWRs of 35% - 40%, 20%, and 5%, respectively.

This analysis underscores the critical importance of climate-responsive building envelope design in BSk climatic regions, which exhibit both heating and cooling demands. Achieving optimal energy performance necessitates a strategic integration of façade orientation, glazing type, and WWR. Façades oriented toward the south, SSE, and SSW consistently demonstrate the highest potential for energy savings, particularly when combined with double or triple glazing, due to their capacity to harness passive solar heating. In contrast, minimizing glazing on east and west-facing façades is essential to reduce excessive solar gains and mitigate cooling energy penalties during warmer periods.

3.3. Arid, Stepped, and Hot (BSh) Climate—Kandahar

Figure 9 illustrates the relative energy efficiency associated with varying WWRs, glazing types, and façade orientations for a residential building located in Kandahar, a city situated in southern Afghanistan's hot semi-arid (BSh) climate.



Orientation

S-| = Single glazing , D-|| = Double glazing , T=||| = Triple glazing

WWR (%)	N			NNE			NE			ENE			E			ESE			SE			SSE		
	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	1.3	0.7	0.1	2.7	1.8	0.8	4.7	3.2	1.7	6.6	4.9	2.9	7.6	5.7	3.5	7.6	5.6	3.2	6.6	4.5	2.5	4.7	2.8	1.3
10	3.0	1.8	0.6	5.7	3.6	1.8	9.4	6.7	3.7	13.1	9.8	5.8	15.4	11.6	6.9	15.4	11.4	6.6	13.5	9.3	5.1	10.1	6.1	2.9
15	4.7	2.9	1.2	8.6	5.7	2.8	14.2	10.2	5.8	19.8	14.9	8.9	23.3	17.6	10.5	23.4	17.4	10.2	20.9	14.3	7.9	15.7	9.5	4.6
20	6.4	4.1	1.7	11.4	7.7	3.9	18.9	13.6	7.8	26.4	19.8	11.9	31.3	23.6	14.2	31.6	23.6	13.9	28.2	19.5	10.8	21.5	13.1	6.4
25	8.0	5.2	2.3	14.4	9.7	4.9	23.5	17.0	9.8	33.0	24.9	14.9	39.3	29.7	16.8	39.9	29.7	17.5	35.8	24.7	13.6	27.4	16.9	8.4
30	9.6	6.4	2.9	17.2	11.5	6.0	28.2	20.4	11.8	39.6	29.9	17.9	47.0	35.8	21.7	48.1	36.0	21.2	43.2	30.1	16.7	33.4	20.8	10.3
35	11.3	7.5	3.5	20.0	13.5	7.2	32.7	23.8	13.8	46.0	34.8	21.0	54.7	41.8	25.4	56.0	42.2	25.0	50.7	35.5	19.6	39.2	24.7	12.3
40	12.9	8.7	4.1	22.7	15.5	8.2	37.0	27.1	15.8	52.3	39.8	24.1	62.3	47.9	29.1	64.0	48.5	28.8	57.9	41.0	22.8	44.8	28.6	14.3
45	14.4	9.8	4.7	25.3	17.4	9.3	41.3	30.5	17.9	58.4	44.6	27.0	69.6	53.9	32.8	71.8	54.7	32.6	64.9	46.4	25.8	50.3	32.5	16.5
50	16.0	11.0	5.4	28.0	19.4	10.5	45.4	33.7	19.8	64.5	49.4	30.1	77.1	59.7	36.6	79.4	60.9	36.4	71.8	51.8	29.0	55.5	36.4	18.7
55	17.6	12.3	6.2	30.6	21.4	11.6	49.6	37.1	21.9	70.5	54.4	33.2	84.3	65.7	40.4	86.8	67.2	40.2	78.5	57.2	32.2	60.6	40.5	21.0
60	19.1	13.5	6.7	33.0	23.4	12.8	53.7	40.3	24.0	76.5	59.1	36.2	91.3	71.6	44.2	94.1	73.2	44.1	85.0	62.4	35.4	65.5	44.2	23.2
65	20.5	14.7	7.5	35.5	25.4	14.0	57.7	43.6	26.0	82.2	63.9	39.3	98.3	77.5	48.0	101.2	79.3	48.0	91.4	67.6	38.7	70.2	47.8	25.5
70	22.0	16.0	8.3	37.9	27.4	15.2	61.8	46.7	28.1	88.0	68.7	42.5	105.2	83.2	51.7	108.3	85.3	51.9	97.6	72.8	41.9	74.8	51.5	27.8

WWR (%)	S			SSW			SW			WSW			W			WNW			NW			NNW		
	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	3.7	2.1	1.0	3.7	2.2	0.9	4.3	2.9	1.5	4.9	3.6	1.9	4.7	3.5	1.9	4.0	2.9	1.6	2.9	2.1	1.0	1.9	1.2	0.4
10	7.7	4.5	2.1	7.7	4.7	2.2	9.1	6.2	3.3	10.0	7.3	4.1	9.7	7.2	4.1	8.2	6.0	3.4	5.9	4.2	2.2	3.9	2.6	1.2
15	12.0	7.1	3.4	12.0	7.3	3.5	14.0	9.7	5.1	15.3	11.2	6.3	14.8	10.9	6.3	12.5	9.2	5.2	9.1	6.5	3.5	6.1	4.0	1.9
20	16.7	9.8	4.7	16.7	10.1	4.9	19.1	13.1	7.0	20.6	15.1	8.6	19.8	14.8	8.6	16.7	12.4	7.1	12.3	8.9	4.8	8.2	5.6	2.7
25	21.5	12.7	6.1	21.4	13.1	6.4	24.3	16.8	8.9	26.1	19.2	11.0	25.1	18.7	10.8	21.1	15.7	9.0	15.5	11.1	6.1	10.4	7.1	3.6
30	26.2	15.8	7.4	26.1	16.1	7.8	29.5	20.4	11.0	31.5	23.3	13.4	30.2	22.5	13.2	25.3	18.8	10.8	18.6	13.4	7.4	12.5	8.7	4.3
35	30.7	18.9	9.0	30.8	19.3	9.4	34.7	24.0	13.1	37.0	27.3	15.8	35.3	26.4	15.5	29.5	22.0	12.7	21.7	15.8	8.6	14.5	10.1	5.1
40	35.2	22.0	10.6	35.4	22.4	11.1	39.9	27.8	15.1	42.3	31.4	18.1	40.4	30.4	17.8	33.8	25.2	14.6	24.8	18.0	9.9	16.7	11.7	5.9
45	39.5	25.0	12.2	39.9	25.6	12.8	44.9	31.6	17.3	47.7	35.4	20.6	45.6	34.2	20.2	38.0	28.3	16.6	27.9	20.3	11.3	18.8	13.2	6.9
50	43.7	28.3	14.0	44.4	28.9	14.6	50.0	35.4	19.5	53.2	39.6	23.0	50.6	38.2	22.5	42.1	31.6	18.5	31.1	22.7	12.6	21.0	14.9	7.7
55	47.6	31.4	15.8	48.9	32.1	16.4	55.1	39.3	21.7	58.6	43.8	25.7	55.6	42.1	25.0	46.4	34.8	20.5	34.2	25.0	14.1	23.2	16.5	8.7
60	51.5	34.4	17.7	53.2	35.4	18.1	60.0	43.2	23.9	63.8	48.0	28.2	60.7	46.1	27.5	50.6	38.0	22.5	37.2	27.3	15.5	25.5	18.1	9.6
65	55.2	37.4	19.4	57.4	38.5	20.1	65.0	47.0	26.2	69.2	52.2	30.7	65.8	50.0	29.9	54.7	41.3	24.5	40.4	29.6	16.9	27.6	19.7	10.6
70	58.6	40.4	21.3	61.6	41.6	22.0	70.1	50.7	28.6	74.5	56.3	33.3	70.8	54.0	32.4	58.9	44.5	26.5	43.5	32.1	18.3	29.9	21.4	11.5

Cooling - Relative Energy Efficiency (%)

Orientation

S-| = Single glazing , D-|| = Double glazing , T=||| = Triple glazing

WWR (%)	N			NNE			NE			ENE			E			ESE			SE			SSE		
	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	1.4	0.6	0.2	1.3	0.6	0.4	0.7	0.2	0.1	-0.6	-0.7	-0.5	-2.2	-2.0	-1.5	-3.6	-3.2	-2.3	-4.6	-4.0	-2.9	-5.2	-4.5	-3.0
10	2.8	1.2	0.6	2.6	1.2	0.6	1.5	0.6	0.2	-0.8	-1.2	-1.0	-3.6	-3.6	-2.7	-5.9	-5.7	-4.0	-7.8	-7.2	-5.2	-9.0	-8.1	-5.7
15	4.2	1.8	0.9	4.0	1.8	0.8	2.4	0.9	0.4	-0.8	-1.5	-1.2	-4.6	-4.9	-3.6	-7.8	-7.7	-5.7	-10.3	-9.9	-7.2	-11.9	-11.2	-8.0
20	5.5	2.4	1.2	5.3	2.4	1.0	3.4	1.4	0.5	-0.7	-1.8	-1.5	-5.3	-5.9	-4.6	-9.1	-9.4	-7.1	-12.1	-12.1	-9.0	-14.1	-13.7	-10.1
25	7.1	3.2	1.5	6.8	2.9	1.4	4.5	1.9	0.7	-0.4	-1.9	-1.6	-5.6	-6.7	-5.3	-10.1	-10.8	-8.3	-13.3	-13.7	-10.5	-15.4	-15.7	-11.8
30	8.5	3.7	1.8	8.1	3.6	1.6	5.6	2.3	0.9	0.0	-2.0	-1.9	-5.9	-7.6	-6.0	-10.7	-12.0	-9.4	-14.1	-15.0	-12.0	-16.4	-17.1	-13.3
35	9.8	4.3	2.1	9.4	4.2	1.9	6.5	2.8	1.0	0.2	-2.1	-2.1	-6.1	-8.2	-6.6	-11.0	-12.8	-10.4	-14.6	-16.1	-13.2	-17.0	-18.3	-14.7
40	11.1	5.0	2.3	10.6	4.8	2.1	7.5	3.2	1.3	0.7	-2.1	-2.3	-6.1	-8.6	-7.2	-11.2	-13.5	-11.3	-14.8	-16.9	-14.1	-17.4	-19.3	-15.9
45	12.4	5.7	2.5	11.9	5.4	2.4	8.5	3.7	1.4	1.2	-2.1	-2.4	-5.9	-9.0	-7.8	-11.2	-14.1	-12.0	-15.0	-17.5	-15.0	-17.5	-19.9	-16.7
50	13.7	6.3	2.8	13.2	6.0	2.7	9.5	4.2	1.6	1.8	-2.0	-2.4	-5.6	-9.4	-8.2	-10.9	-14.5	-12.7	-14.8	-18.0	-15.8	-17.5	-20.4	-17.6
55	15.2	6.8	3.2	14.4	6.6	2.9	10.7	4.6	1.9	2.5	-1.9	-2.5	-5.1	-9.5	-8.6	-10.5	-14.7	-13.2	-14.5	-18.3	-16.4	-17.1	-20.8	-18.2
60	16.5	7.6	3.4	15.8	7.2	3.2	11.7	5.2	2.1	3.2	-1.8	-2.6	-4.6	-9.6	-9.0	-10.1	-14.8	-13.6	-14.0	-18.4	-16.8	-16.7	-20.9	-18.7
65	17.9	8.2	3.6	17.2	7.9	3.5	12.7	5.7	2.3	3.9	-1.5	-2.6	-3.8	-9.6	-9.2	-9.5	-14.8	-14.0	-13.5	-18.5	-17.2	-16.4	-21.0	-19.1
70	19.5	9.0	4.0	18.7	8.6	3.9	14.1	6.4	2.5	4.9	-1.2	-2.6	-3.0	-9.4	-9.4	-8.6	-14.7	-14.2	-12.7	-18.4	-17.4	-15.7	-20.9	-19.4

WWR (%)	S			SSW			SW			WSW			W			WNW			NW			NNW		
	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	-5.2	-4.4	-2.9	-3.9	-3.3	-2.2	-2.5	-2.4	-1.5	-1.2	-1.3	-0.8	-0.2	-0.5	-0.4	0.7	0.2	0.1	1.3	0.6	0.2	1.4	0.7	0.4
10	-9.0	-8.0	-5.4	-6.9	-6.2	-4.1	-4.4	-4.3	-2.9	-2.2	-2.4	-1.7	-0.2	-0.9	-0.7	1.5	0.5	0.1	2.5	1.0	0.4	2.9	1.3	0.6
15	-12.0	-11.1	-7.6	-9.0	-8.5	-5.8	-5.8	-5.8	-4.1	-2.7	-3.3	-2.4	0.0	-1.1	-1.0	2.4	0.8	0.2	3.8	1.6	0.8	4.3	1.9	1.0
20	-14.2	-13.6	-9.7	-10.8	-10.3	-7.3	-6.8	-7.2	-5.2	-3.2	-4.2	-3.1	0.2	-1.3	-1.2	3.3	1.0	0.4	5.0	2.2	1.0	5.6	2.5	1.2
25	-15.7	-15.7	-11.4	-12.0	-11.9	-8.7	-7.6	-8.3	-6.2	-3.2	-4.8	-3.7	0.7	-1.4	-1.3	4.3	1.5	0.6	6.5	2.8	1.3	7.1	3.2	1.5
30	-16.8	-17.3	-13.0	-13.0	-13.3	-10.0	-8.0	-9.2	-7.1	-3.3	-5.3	-4.2	1.2	-1.4	-1.6	5.3	1.9	0.7	7.8	3.4	1.6	8.6	3.8	1.8
35	-17.5	-18.6	-14.4	-13.6	-14.4	-11.1	-8.4	-10.1	-7.9	-3.3	-5.7	-4.6	1.7	-1.4	-1.7	6.1	2.2	0.8	9.0	3.9	1.9	9.9	4.4	2.0
40	-17.9	-19.6	-15.7	-14.0	-15.4	-12.0	-8.5	-10.8	-8.6	-3.2	-6.2	-5.1	2.3	-1.4	-1.8	7.1	2.6	1.0	10.3	4.5	2.1	11.2	5.0	2.4
45	-18.1	-20.5	-16.6	-14.1	-16.1	-12.9	-8.5	-11.3	-9.2	-3.0	-6.4	-5.5	2.7	-1.3	-1.9	8.0	2.9	1.0	11.4	5.1	2.3	12.5	5.7	2.6
50	-18.1	-21.0	-17.5	-14.1	-16.6	-13.6	-8.3	-11.7	-9.8	-2.5	-6.7	-5.9	3.4	-1.3	-2.0	9.0	3.4	1.2	12.7	5.7	2.5	13.8	6.3	2.9
55	-17.9	-21.3	-18.2	-13.8	-16.9	-14.3	-7.9	-11.9	-10.4	-2.0	-6.7	-6.2	4.2	-1.2	-2.0	10.1	3.9	1.4	14.0	6.3	2.8	15.2	7.0	3.1
60	-17.5	-21.5	-18.7	-13.5	-17.1	-14.8	-7.5	-12.0	-10.8	-1.4	-6.8	-6.4	4.9	-1.0	-2.0	11.2	4.4	1.5	15.3	6.9	3.0	16.7	7.6	3.5
65	-17.1	-21.7	-19.2	-13.0	-17.2	-15.3	-6.8	-12.2	-11.1	-0.7	-6.7	-6.7	5.8	-0.9	-2.0	12.4	4.8	1.6	16.6	7.6	3.4	18.0	8.2	3.7
70	-16.4	-21.7	-19.6	-12.3	-17.1	-15.5	-5.9	-12.0	-11.3	0.2	-6.6	-6.9	6.8	-0.5	-1.9	13.8	5.4	1.9	18.1	8.3	3.7	19.7	9.1	4.1

Heating - Relative Energy Efficiency (%)

Orientation

S-| = Single glazing , D-|| = Double glazing , T=||| = Triple glazing

WWR (%)	N			NNE			NE			ENE			E			ESE			SE			SSE		
	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	2.7	1.4	0.4	4.0	2.4	1.2	5.4	3.5	1.9	6.0	4.1	2.4	5.5	3.7	2.0	4.0	2.3	0.9	2.0	0.4	-0.4	-0.5	-1.7	-1.7
10	5.8	3.0	1.2	8.2	4.8	2.4	10.9	7.3	4.0	12.3	8.7	4.8	11.8	8.0	4.3	9.5	5.7	2.6	5.7	2.1	-0.1	1.1	-2.1	-2.8
15	8.9	4.7	2.1	12.6	7.4	3.6	16.6	11.1	6.2	19.0	13.4	7.7	18.8	12.6	6.9	15.6	9.7	4.5	10.5	4.5	0.7	3.8	-1.7	-3.4
20	11.9	6.5	2.9	16.7	10.0	4.9	22.3	14.9	8.3	25.7	18.1	10.4	26.0	17.7	9.6	22.5	14.2	6.8	16.1	7.4	1.8	7.4	-0.6	-3.6
25	15.1	8.3	3.8	21.2	12.6	6.3	28.0	18.9	10.5	32.7	23.0	13.2	33.6	23.0	11.6	29.8	19.0	9.2	22.5	11.0	3.1	12.0	1.2	-3.4
30	18.2	10.1	4.7	25.3	15.2	7.7	33.8	22.7	12.7	39.6	27.8	16.1	41.1	28.2	15.6	37.4	24.1	11.8	29.1	15.0	4.7	17.0	3.6	-3.0
35	21.1	11.8	5.5	29.4	17.7	9.1	39.2	26.5	14.8	46.2	32.7	18.9	48.6	33.6	18.8	45.0	29.3	14.6	36.1	19.4	6.5	22.2	6.3	-2.4
40	24.0	13.6	6.4	33.3	20.3	10.3	44.5	30.4	17.0	53.0	37.6	21.8	56.1	39.3	21.9	52.8	34.9	17.5	43.1	24.1	8.6	27.4	9.3	-1.6
45	26.8	15.4	7.2	37.1	22.8	11.7	49.7	34.2	19.3	59.6	42.5	24.7	63.8	44.9	25.0	60.6	40.6	20.6	50.0	28.9	10.8	32.8	12.6	-0.2
50	29.7	17.2	8.2	41.1	25.4	13.2	54.9	37.9	21.5	66.3	47.4	27.7	71.4	50.4	28.5	68.5	46.4	23.7	57.0	33.8	13.3	38.0	16.0	1.1
55	32.7	19.1	9.3	45.0	28.0	14.6	60.3	41.7	23.8	73.0	52.5	30.7	79.1	56.3	31.8	76.3	52.5	27.0	64.1	38.9	15.8	43.5	19.7	2.8
60	35.6	21.0	10.1	48.8	30.6	16.0	65.4	45.6	26.1	79.6	57.3	33.6	86.8	62.0	35.2	84.0	58.4	30.4	71.1	44.0	18.6	48.7	23.3	4.5
65	38.5	22.9	11.1	52.6	33.2	17.5	70.5	49.3	28.3	86.1	62.4	36.7	94.4	67.9	38.8	91.7	64.4	34.0	77.8	49.2	21.5	53.9	26.8	6.4
70	41.5	25.0	12.3	56.5	36.0	19.0	75.9	53.1	30.6	93.0	67.5	39.9	102.2	73.9	42.4	99.6	70.6	37.7	84.9	54.4	24.5	59.2	30.6	8.4

WWR (%)	S			SSW			SW			WSW			W			WNW			NW			NNW		
	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	-1.5	-2.3	-1.9	-0.1	-1.1	-1.2	1.9	0.6	0.0	3.7	2.3	1.1	4.5	3.0	1.6	4.7	3.2	1.8	4.2	2.7	1.3	3.3	1.9	0.8
10	-1.3	-3.5	-3.3	0.9	-1.5	-1.9	4.7	2.0	0.4	7.9	4.9	2.4	9.5	6.3	3.4	9.8	6.5	3.5	8.5	5.3	2.7	6.8	3.9	1.8
15	0.0	-4.0	-4.3	3.0	-1.1	-2.3	8.2	3.9	0.9	12.5	7.9	3.9	14.8	9.8	5.3	14.9	10.0	5.4	12.9	8.2	4.3	10.4	5.9	2.9
20	2.5	-3.8	-5.0	5.9	-0.2	-2.4	12.2	5.9	1.9	17.4	11.0	5.5	20.0	13.5	7.4	20.0	13.4	7.4	17.3	11.1	5.8	13.8	8.1	3.9
25	5.8	-2.9	-5.4	9.4	1.1	-2.3	16.7	8.5	2.8	22.9	14.5	7.3	25.8	17.3	9.5	25.3	17.2	9.6	22.1	13.9	7.3	17.5	10.4	5.1
30	9.4	-1.4	-5.6	13.1	2.9	-2.2	21.5	11.2	3.9	28.2	18.0	9.2	31.4	21.1	11.7	30.6	20.7	11.6	26.4	16.8	9.0	21.0	12.5	6.1
35	13.2	0.3	-5.4	17.2	4.8	-1.7	26.3	13.9	5.2	33.7	21.6	11.1	36.9	25.0	13.8	35.6	24.2	13.6	30.7	19.7	10.5	24.4	14.5	7.1
40	17.3	2.4	-5.0	21.4	6.9	-0.9	31.4	17.1	6.5	39.1	25.2	13.0	42.7	28.9	16.0	40.8	27.8	15.6	35.1	22.5	12.0	27.9	16.7	8.3
45	21.4	4.6	-4.4	25.9	9.5	-0.1	36.4	20.3	8.1	44.7	29.0	15.1	48.3	32.9	18.2	46.0	31.3	17.6	39.3	25.4	13.6	31.3	18.9	9.5
50	25.6	7.3	-3.5	30.3	12.2	0.9	41.8	23.7	9.7	50.7	32.9	17.2	54.0	36.9	20.5	51.1	35.0	19.6	43.8	28.3	15.2	34.8	21.2	10.6
55	29.8	10.0	-2.4	35.1	15.2	2.1	47.2	27.3	11.3	56.6	37.1	19.5	59.8	40.9	22.9	56.5	38.7	21.9	48.2	31.3	16.9	38.4	23.6	11.8
60	34.0	12.9	-1.1	39.7	18.3	3.3	52.6	31.1	13.2	62.4	41.2	21.7	65.6	45.1	25.5	61.7	42.4	24.0	52.5	34.2	18.6	42.2	25.7	13.1
65	38.0	15.7	0.2	44.4	21.3	4.8	58.2	34.8	15.1	68.5	45.5	24.0	71.5	49.2	27.8	67.1	46.1	26.1	56.9	37.2	20.3	45.6	27.9	14.3
70	42.3	18.7	1.6	49.3	24.5	6.5	64.2	38.7	17.2	74.7	49.8	26.4	77.6	53.5	30.5	72.7	49.9	28.4	61.6	40.4	22.1	49.5	30.5	15.6

Total - Relative Energy Efficiency (%)

Figure 9. Energy efficiency heatmaps by orientation, WWR, and glazing type in Kandahar (BSh).

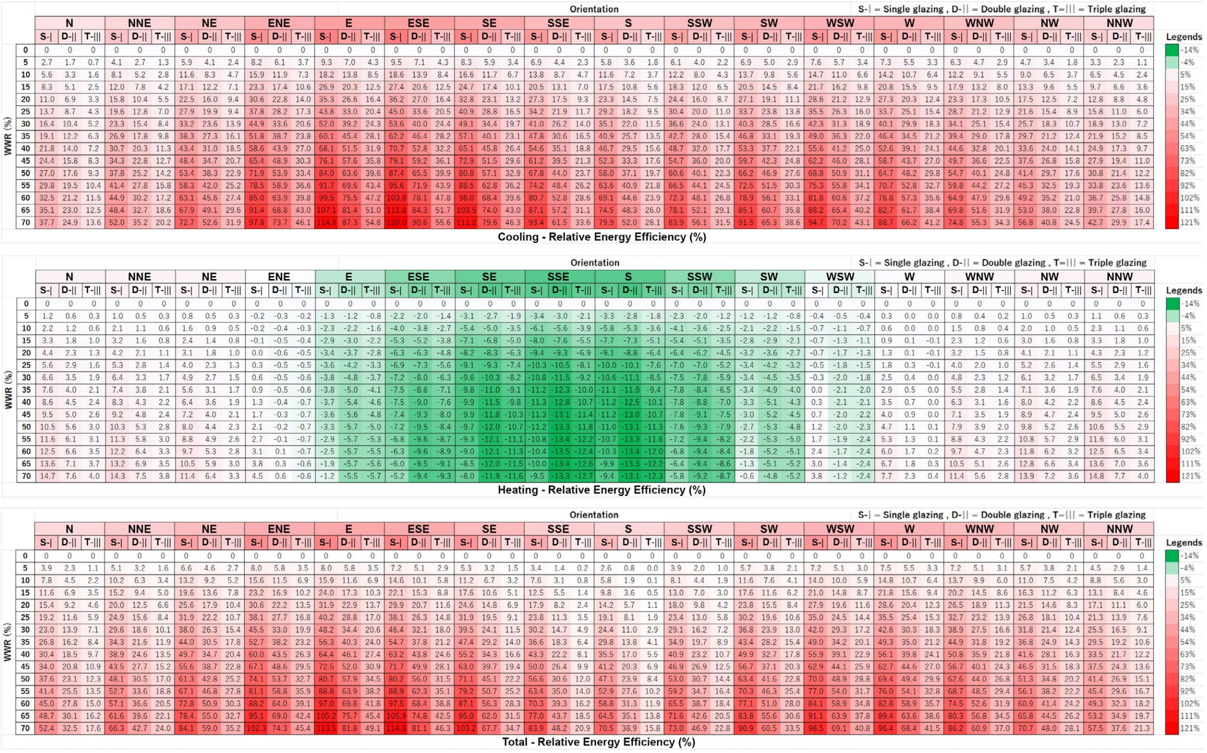
In this region, cooling dominates the annual energy demand profile due to prolonged periods of elevated ambient temperatures. The cooling efficiency heatmaps reveal a consistent trend: as WWR increases, cooling performance deteriorates, particularly on east-, west-, and adjacent-oriented façades (ENE, ESE, WNW, WSW) that receive high solar exposure during peak hours. Among glazing types, single glazing results in the greatest inefficiencies, while double and triple glazing offer only limited mitigation—especially under larger WWRs.

Heating efficiency in Kandahar follows patterns observed in other climates, with modest improvements noted on south-facing façades as WWR increases. Triple-glazed windows in these orientations can reduce heating loads by up to 22%. However, due to the mildness of Kandahar's winters, these gains contribute little to the building's total annual energy performance.

The total energy efficiency heatmap confirms that cooling demand is the primary determinant of energy performance in this climate. Larger WWRs lead to higher overall energy consumption across all orientations and glazing types. A modest exception is seen on south-facing façades with triple glazing and moderate WWRs (10% - 30%), where annual energy savings can reach up to 5.6%. Beyond this range, energy efficiency either plateaus or declines.

3.4. Arid, Desert, and Hot (BWh) Climate—Farah

Figure 10 presents the energy efficiency analysis for various WWRs, glazing types, and façade orientations in Farah, a southwestern city located in Afghanistan's hot desert (BWh) climate zone. Compared to Kandahar, Farah experiences more extreme summer temperatures and even lower seasonal variation, intensifying its cooling-dominated energy profile.



Orientation

S-| = Single glazing , D-|| = Double glazing , T=||| = Triple glazing

WWR (%)	N			NNE			NE			ENE			E			ESE			SE		
	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	2.7	1.7	0.7	4.1	2.7	1.3	5.9	4.1	2.4	8.2	6.1	3.7	9.3	7.0	4.3	9.5	7.1	4.3	8.3	5.9	3.4
10	5.6	3.3	1.6	8.1	5.2	2.8	11.6	8.3	4.7	15.9	11.9	7.3	18.2	13.8	8.5	18.6	13.9	8.4	16.6	11.7	6.7
15	8.3	5.1	2.5	12.0	7.8	4.2	17.1	12.2	7.1	23.3	17.4	10.6	26.9	20.3	12.5	27.4	20.6	12.5	24.7	17.4	10.1
20	11.0	6.9	3.3	15.8	10.4	5.5	22.5	16.0	9.4	30.6	22.8	14.0	35.3	26.6	16.4	36.2	27.0	16.4	32.8	23.1	13.2
25	13.7	8.7	4.3	19.6	12.8	7.0	27.9	19.9	9.4	37.8	28.2	17.3	43.8	33.0	20.4	45.0	33.6	20.5	40.9	28.8	16.5
30	16.4	10.4	5.2	23.3	15.4	8.4	33.2	23.6	13.9	44.9	33.6	20.6	52.0	39.2	24.3	53.6	40.0	24.4	49.1	34.4	19.7
35	19.1	12.2	6.3	26.9	17.8	9.8	38.3	27.3	16.1	51.8	38.7	23.8	60.1	45.4	28.1	62.2	46.4	28.2	57.1	40.1	23.1
40	21.8	14.0	7.2	30.7	20.3	11.3	43.4	31.0	18.5	58.6	43.9	27.0	68.1	51.5	31.9	70.7	52.8	32.2	65.1	45.8	26.4
45	24.4	15.8	8.3	34.3	22.8	12.7	48.4	34.7	20.7	65.4	48.9	30.3	76.1	57.6	35.8	79.1	59.2	36.1	72.9	51.5	29.6
50	27.0	17.6	9.3	37.8	25.2	14.2	53.4	38.3	22.9	71.9	53.9	33.4	84.0	63.6	39.6	87.4	65.5	39.9	80.8	57.1	32.9
55	29.8	19.5	10.4	41.4	27.8	15.8	58.3	42.0	25.2	78.5	58.9	36.6	91.7	69.6	43.4	95.6	71.9	43.9	88.5	62.8	36.2
60	32.5	21.2	11.5	44.9	30.2	17.2	63.1	45.6	27.4	85.0	63.9	39.8	99.5	75.5	47.2	103.8	78.1	47.8	96.0	68.4	39.6
65	35.1	23.0	12.5	48.4	32.7	18.6	67.9	49.1	29.6	91.4	68.8	43.0	107.1	81.4	51.0	111.8	84.3	51.7	103.5	74.0	43.0
70	37.7	24.9	13.6	52.0	35.2	20.2	72.7	52.6	31.9	97.8	73.7	46.1	114.8	87.3	54.8	120.0	90.6	55.6	111.2	79.6	46.3

WWR (%)	SSE			S			SSW			SW			WSW			W			WNW			NW			NNW		
	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	6.9	4.4	2.3	5.8	3.6	1.8	6.1	4.0	2.2	6.9	5.0	2.9	7.6	5.7	3.4	7.3	5.5	3.3	6.3	4.7	2.9	4.7	3.4	1.8	3.3	2.3	1.1
10	13.8	8.7	4.7	11.6	7.2	3.7	12.2	8.0	4.3	13.7	9.8	5.6	14.7	11.0	6.6	14.2	10.7	6.4	12.2	9.1	5.5	9.0	6.5	3.7	6.5	4.5	2.4
15	20.5	13.1	7.0	17.5	10.8	5.6	18.3	12.0	6.5	20.5	14.5	8.4	21.7	16.2	9.8	20.8	15.5	9.5	17.9	13.2	8.0	13.3	9.6	5.5	9.7	6.6	3.6
20	27.3	17.5	9.3	23.3	14.5	7.5	24.4	16.0	8.7	27.1	19.1	11.1	28.6	21.2	12.9	27.3	20.3	12.4	23.3	17.3	10.5	17.5	12.5	7.2	12.8	8.8	4.8
25	34.2	21.9	11.7	29.2	18.2	9.5	30.4	20.0	11.0	33.7	23.8	13.8	35.5	26.3	16.0	33.7	25.1	15.4	28.7	21.2	12.9	21.6	15.4	8.9	15.8	11.0	6.0
30	41.0	26.2	14.0	35.1	22.0	11.5	36.6	24.0	13.1	40.3	28.5	16.6	42.3	31.3	18.9	40.1	29.9	18.3	34.1	25.1	15.4	25.7	18.3	10.7	18.9	13.0	7.2
35	47.8	30.6	16.5	40.9	25.7	13.5	42.7	28.0	15.4	46.8	33.1	19.3	49.0	36.3	22.0	46.4	34.5	21.2	39.4	29.0	17.8	29.7	21.2	12.4	21.9	15.2	8.5
40	54.6	35.1	18.8	46.7	29.5	15.6	48.7	32.0	17.7	53.3	37.7	22.1	55.6	41.2	25.0	52.6	39.1	24.1	44.6	32.8	20.1	33.6	24.0	14.1	24.9	17.3	9.7
45	61.2	39.5	21.3	52.3	33.3	17.6	54.7	36.0	20.0	59.7	42.3	24.8	62.2	46.0	28.1	58.7	43.7	27.0	49.7	36.6	22.5	37.6	26.8	15.8	27.9	19.4	11.0
50	67.8	44.0	23.7	58.0	37.1	19.7	60.6	40.1	22.3	66.2	46.9	27.6	68.8	50.9	31.1	64.7	48.2	29.8	54.7	40.1	24.8	41.4	29.7	17.6	30.8	21.4	12.2
55	74.2	48.4	26.2	63.6	40.9	21.8	66.5	44.1	24.5	72.5	51.5	30.3	75.3	55.8	34.1	70.7	52.8	32.7	59.8	44.2	27.2	45.3	32.5	19.3	33.8	23.6	13.6
60	80.7	52.8	28.6	69.1	44.6	23.9	72.3	48.1	26.8	78.9	56.1	33.1	81.8	60.6	37.2	76.8	57.3	35.6	64.9	47.9	29.6	49.2	35.2	21.0	36.7	25.8	14.8
65	87.1	57.2	31.1	74.5	48.3	26.0	78.1	52.1	29.1	85.1	60.7	35.8	88.2	65.4	40.2	82.7	61.7	38.4	69.8	51.6	31.9	53.0	38.0	22.8	39.7	27.8	16.0
70	93.4	61.5	33.6	79.9	52.0	28.1	83.9	56.1	31.5	91.5	65.3	38.6	94.7	70.2	43.1	88.7	66.2	41.2	74.8	55.3	34.3	56.8	40.8	24.5	42.7	29.9	17.4

Cooling - Relative Energy Efficiency (%)

Orientation

S-| = Single glazing , D-|| = Double glazing , T=||| = Triple glazing

WWR (%)	N			NNE			NE			ENE			E			ESE			SE		
	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	1.2	0.6	0.3	1.0	0.5	0.3	0.8	0.5	0.3	-0.2	-0.3	-0.2	-1.3	-1.2	-0.8	-2.2	-2.0	-1.4	-3.1	-2.7	-1.9
10	2.2	1.2	0.6	2.1	1.1	0.6	1.6	0.9	0.5	-0.2	-0.4	-0.3	-2.3	-2.2	-1.6	-4.0	-3.8	-2.7	-5.4	-5.0	-3.5
15	3.3	1.8	1.0	3.2	1.6	0.8	2.4	1.4	0.8	-0.1	-0.5	-0.4	-2.9	-3.0	-2.2	-5.3	-5.2	-3.8	-7.1	-6.8	-5.0
20	4.4	2.3	1.3	4.2	2.1	1.1	3.1	1.8	1.0	0.0	-0.6	-0.5	-3.4	-3.7	-2.8	-6.3	-6.3	-4.8	-8.2	-8.3	-6.3
25	5.6	2.9	1.6	5.3	2.8	1.4	4.0	2.3	1.3	0.3	-0.5	-0.5	-3.6	-4.2	-3.3	-6.9	-7.3	-5.6	-9.1	-9.3	-7.4
30	6.6	3.5	1.9	6.4	3.3	1.7	4.9	2.7	1.5	0.6	-0.5	-0.6	-3.8	-4.8	-3.7	-7.2	-8.0	-6.3	-9.6	-10.3	-8.2
35	7.6	4.0	2.1	7.4	3.8	2.1	5.6	3.1	1.7	0.9	-0.5	-0.6	-3.8	-5.0	-4.1	-7.5	-8.6	-7.1	-9.8	-11.0	-9.1
40	8.6	4.5	2.4	8.3	4.3	2.2	6.4	3.6	1.9	1.3	-0.4	-0.7	-3.7	-5.4	-4.6	-7.5	-9.0	-7.6	-9.9	-11.5	-9.8
45	9.5	5.0	2.6	9.2	4.8	2.4	7.2	4.0	2.1	1.7	-0.3	-0.7	-3.6	-5.6	-4.8	-7.4	-9.3	-8.0	-9.9	-11.8	-10.3
50	10.5	5.6	3.0	10.3	5.3	2.8	8.0	4.4	2.3	2.1	-0.2	-0.7	-3.3	-5.7	-5.0	-7.2	-9.5	-8.4	-9.7	-12.0	-10.7
55	11.6	6.1	3.1	11.3	5.8	3.0	8.8	4.9	2.6	2.7	-0.1	-0.7	-2.9	-5.7	-5.3	-6.8	-9.6	-8.7	-9.3	-12.1	-11.1
60	12.5	6.6	3.5	12.2	6.4	3.3	9.7	5.3	2.8	3.1	0.1	-0.7	-2.5	-5.7	-5.5	-6.3	-9.6	-8.9	-9.0	-12.1	-11.3
65	13.6	7.1	3.7	13.2	6.9	3.5	10.5	5.9	3.0	3.8	0.3	-0.6	-1.9	-5.7	-5.6	-6.0	-9.5	-9.1	-8.5	-12.0	-11.5
70	14.7	7.6	4.0	14.3	7.5	3.8	11.4	6.4	3.3	4.5	0.6	-0.6	-1.2	-5.5	-5.7	-5.2	-9.4	-9.3	-8.0	-11.9	-11.6

WWR (%)	SSE			S			SSW			SW			WSW			W			WNW			NW			NNW		
	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	-3.4	-3.0	-2.1	-3.3	-2.8	-1.8	-2.3	-2.0	-1.2	-1.2	-1.2	-0.8	-0.4	-0.5	-0.4	0.3	0.0	0.0	0.8	0.4	0.2	1.0	0.5	0.3	1.1	0.6	0.3
10	-6.1	-5.6	-3.9	-5.8	-5.3	-3.6	-4.1	-3.6	-2.5	-2.1	-2.2	-1.5	-0.7	-1.1	-0.7	0.6	0.0	0.0	1.5	0.8	0.4	2.0	1.0	0.5	2.3	1.1	0.6
15	-8.0	-7.6	-5.5	-7.7	-7.3	-5.1	-5.4	-5.1	-3.5	-2.8	-2.9	-2.1	-0.7	-1.3	-1.1	0.9	0.1	-0.1	2.3	1.2	0.6	3.0	1.6	0.8	3.3	1.8	1.0
20	-9.4	-9.3	-6.9	-9.1	-8.8	-6.4	-6.4	-6.2	-4.5	-3.2	-3.6	-2.7	-0.7	-1.7	-1.3	1.3	0.1	-0.1	3.2	1.5	0.8	4.1	2.1	1.1	4.3	2.3	1.2
25	-10.3	-10.5	-8.1	-10.0	-10.1	-7.6	-7.0	-7.0	-5.2	-3.4	-4.2	-3.2	-0.5	-1.8	-1.5	1.8	0.3	-0.1	4.0	2.0	1.0	5.2	2.6	1.4	5.5	2.9	1.6
30	-10.8	-11.5	-9.2	-10.6	-11.1	-8.5	-7.5	-7.8	-5.9	-3.4	-4.5	-3.5	-0.3	-2.0	-1.8	2.5	0.4	0.0	4.8	2.3	1.2	6.1	3.2	1.7	6.5	3.4	1.9
35	-11.2	-12.3	-10.0	-11.1	-11.9	-9.4	-7.8	-8.4	-6.5	-3.4	-4.9	-4.0	0.0	-2.1	-2.0	2.9	0.5	0.0	5.5	2.8	1.4	7.1	3.6	1.9	7.6	4.0	2.1
40	-11.3	-12.8	-10.7	-11.2	-12.5	-10.1	-7.8	-8.8	-7.0	-3.3	-5.1	-4.3	0.3	-2.1	-2.1	3.5	0.7	0.0	6.3	3.1	1.6	8.0	4.2	2.2	8.6	4.5	2.4
45	-11.3	-13.1	-11.4	-11.2	-13.0	-10.7	-7.8	-9.1	-7.5	-3.0	-5.2	-4.5	0.7	-2.0	-2.2	4.0	0.9	0.0	7.1	3.5	1.9	8.9	4.7	2.4	9.5	5.0	2.6
50	-11.2	-13.3	-11.8	-11.0	-13.1	-11.3	-7.6	-9.3	-7.9	-2.7	-5.3	-4.8	1.2	-2.0	-2.3	4.7	1.1	0.1	7.9	3.9	2.0	9.8	5.2	2.6	10.6	5.5	2.9
55	-10.8	-13.4	-12.2	-10.7	-13.3	-11.6	-7.2	-9.4	-8.2	-2.2	-5.3	-5.0	1.7	-1.9	-2.4	5.3	1.3	0.1	8.8	4.3	2.2	10.8	5.7	2.9	11.6	6.0	3.1
60	-10.4	-13.5	-12.4	-10.3	-13.4	-12.0	-6.8	-9.4	-8.4	-1.8	-5.2	-5.1	2.4	-1.7	-2.4	6.0	1.7	0.2	9.7	4.7	2.3	11.8	6.2	3.2	12.5	6.5	3.4
65	-10.0	-13.4	-12.6	-9.9	-13.3	-12.2	-6.4	-9.4	-8.6	-1.3	-5.1	-5.2	3.0	-1.4	-2.4	6.7	1.8	0.3	10.5	5.1	2.6	12.8	6.6	3.4	13.6	7.0	3.6
70	-9.5	-13.3	-12.7	-9.4	-13.1	-12.3	-5.8	-9.2	-8.7	-0.6	-4.8	-5.2	3.8	-1.2	-2.4	7.7	2.3	0.4	11.4	5.6	2.8	13.9	7.2	3.6	14.8	7.7	4.0

Heating - Relative Energy Efficiency (%)

Orientation

S-| = Single glazing , D-|| = Double glazing , T=||| = Triple glazing

WWR (%)	N			NNE			NE			ENE			E			ESE			SE		
	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	3.9	2.3	1.1	5.1	3.2	1.6	6.6	4.6	2.7	8.0	5.8	3.5	8.0	5.8	3.5	7.2	5.1	2.9	5.3	3.2	1.5
10	7.8	4.5	2.2	10.2	6.3	3.4	13.2	9.2	5.2	15.6	11.5	6.9	15.9	11.6	6.9	14.6	10.1	5.8	11.2	6.7	3.2
15	11.6	6.9	3.5	15.2	9.4	5.0	19.6	13.6	7.8	23.2	16.9	10.2	24.0	17.3	10.3	22.1	15.3	8.8	17.6	10.6	5.1
20	15.4	9.2	4.6	20.0	12.5	6.6	25.6	17.9	10.4	30.6	22.2	13.5	31.9	22.9	13.7	29.9	20.7	11.6	24.6	14.8	6.9
25	19.2	11.6	5.9	24.9	15.6	8.4	31.9	22.2	10.7	38.1	27.7	16.8	40.2	28.8	17.0	38.1	26.3	14.8	31.9	19.5	9.1
30	23.0	13.9	7.1	29.6	18.6	10.1	38.0	26.3	15.4	45.5	33.0	19.9	48.2	34.4	20.6	46.4	32.1	18.0	39.5	24.1	11.5
35	26.8	16.2	8.4	34.3	21.6	11.9	44.0	30.5	17.8	52.7	38.2	23.2	56.3	40.3	24.0	54.7	37.8	21.2	47.4	29.2	14.0
40	30.4	18.5	9.7	38.9	24.6	13.5	49.7	34.7	20.4	60.0	43.5	26.3	64.4	46.1	27.4	63.2	43.8	24.6	55.2	34.3	16.6
45	34.0	20.8	10.9	43.5	27.7	15.2	55.6	38.7	22.8	67.1	48.6	29.5	72.5	52.0	30.9	71.7	49.9	28.1	63.0	39.7	19.4
50	37.6	23.1	12.3	48.1	30.5	17.0	61.3	42.8	25.2	74.1	53.7	32.7	80.7	57.9	34.5	80.2	56.0	31.5	71.1	45.1	22.2
55	41.4	25.5	13.5	52.7	33.6	18.8	67.1	46.8	27.8	81.1	58.8	35.9	88.8	63.9	38.2	88.9	62.3	35.1	79.2	50.7	25.2
60	45.0	27.8	15.0	57.1	36.6	20.5	72.8	50.9	30.3	88.2	64.0	39.1	97.0	69.8	41.8	97.5	68.4	38.8	87.1	56.3	28.3
65	48.7	30.1	16.2	61.6	39.6	22.1	78.4	55.0	32.7	95.1	69.0	42.4	105.2	75.7	45.4	105.9	74.8	42.5	95.0	62.0	31.5
70	52.4	32.5	17.6	66.3	42.7	24.0	84.1	59.0	35.2	102.3	74.3	45.4	113.5	81.8	49.1	114.8	81.1	46.3	103.2	67.7	34.7

WWR (%)	SSE			S			SSW			SW			WSW			W			WNW			NW			NNW		
	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||	S-|	D-||	T-|||
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	3.4	1.4	0.2	2.6	0.8	0.0	3.9	2.0	1.0	5.7	3.8	2.1	7.2	5.1	3.0	7.5	5.5	3.3	7.2	5.1	3.1	5.7	3.8	2.1	4.5	2.9	1.4
10	7.6	3.1	0.8	5.8	1.9	0.1	8.1	4.4	1.9	11.6	7.6	4.1	14.0	10.0	5.9	14.8	10.7	6.4	13.7	9.9	6.0	11.0	7.5	4.2	8.8	5.6	3.0
15	12.5	5.5	1.4	9.8	3.6	0.5	13.0	7.0	3.0	17.6	11.6	6.2	21.0	14.8	8.7	21.8	15.6	9.4	20.2	14.5	8.6	16.3	11.2	6.3	13.1	8.4	4.6
20	17.9	8.2	2.4	14.2	5.7	1.1	18.0	9.8	4.2	23.8	15.5	8.4	27.9	19.6	11.6	28.6	20.4	12.3	26.5	18.9	11.3	21.5	14.6	8.3	17.1	11.1	6.0
25	23.8	11.3	3.5	19.1	8.1	1.9	23.4	13.0	5.8	30.2	19.6	10.6	35.0	24.5	14.4	35.5	25.4	15.3	32.7	23.2	13.9	26.8	18.1	10.4	21.3	13.9	7.6
30	30.2	14.7	4.9	24.4	11.0	2.9	29.1	16.2	7.2	36.8	23.9	13.0	42.0	29.3	17.2	42.6	30.3	18.3	38.9	27.5	16.6	31.8	21.4	12.4	25.5	16.5	9.1
35	36.6	18.3	6.4	29.8	13.8	4.1	34.9	19.7	8.9	43.4	28.2	15.4	49.0	34.2	20.1	49.3	35.0	21.2	44.9	31.8	19.2	36.8	24.9	14.3	29.5	19.2	10.6
40	43.3	22.2	8.1	35.5	17.0	5.5	40.9	23.2	10.7	49.9	32.7	17.8	55.9	39.1	22.9	56.1	39.8	24.1	50.8	35.9	21.8	41.6	28.1	16.3	33.5	21.7	12.2
45	50.0	26.4	9.9	41.2	20.3	6.9	46.9	26.9	12.5	56.7	37.1	20.3	62.9	44.1	25.9	62.7	44.6	27.0	56.7	40.1	24.3	46.5	31.5	18.3	37.5	24.3	13.6
50	56.6	30.6	12.0	47.1	23.9	8.4	53.0	30.7	14.4	63.4	41.6	22.8	70.0	48.9	28.8	69.4	49.4	29.9	62.6	44.0	26.8	51.3	34.8	20.2	41.4	26.9	15.1
55	63.4	35.0	14.0	52.9	27.6	10.2	59.2	34.7	16.4	70.3	46.3	25.4	77.0	54.0	31.7	76.0	54.1	32.8	68.7	48.5	29.4	56.1	38.2	22.2	45.4	29.6	16.7
60	70.3	39.3	16.2	58.8	31.3	11.9	65.5	38.7	18.4	77.1	51.0	28.0	84.1	58.9	34.8	82.8	58.9	35.7	74.5	52.6	31.9	60.9	41.4	24.2	49.3	32.3	18.2
65	77.0	43.7	18.5	64.5	35.1	13.8	71.6	42.6	20.5	83.8	55.6	30.6	91.1	63.9	37.8	89.4	63.6	38.6	80.3	56.8	34.5	65.8	44.5	26.2	53.2	34.9	19.7
70	83.9	48.2	20.9	70.5	38.9	15.8	73.0	46.9	22.8	90.9	60.5	33.5	98.5	69.1	40.8	96.4	68.4	41.5	86.2	60.9	37.0	70.7	48.0	28.1	57.5	37.6	21.3

Total - Relative Energy Efficiency (%)

Figure 10. Energy efficiency heatmaps by orientation, WWR, and glazing type in Farah (BWh).

The cooling efficiency heatmaps clearly demonstrate that increasing WWR results in steep rises in cooling energy demand. This effect is most pronounced on east- and west-facing façades, where extended direct solar exposure during peak hours exacerbates heat gains. Single-glazed windows perform especially poorly under these conditions. While double and triple glazing reduce solar transmission to some extent, their impact remains limited in offsetting the inefficiencies associated with large glazing areas.

Heating energy efficiency maps indicate small improvements with increased WWR on south-facing façades, particularly when using triple glazing. However, the maximum observed heating savings—approximately 14%—have negligible influence on total energy use due to Farah's short and mild winters. This highlights the limited applicability of passive solar heating strategies in extremely hot desert climates.

The total energy performance analysis reinforces the dominant influence of cooling loads. Annual energy consumption increases consistently with larger WWRs across all façade orientations and glazing types. In extreme cases, such as façades with 70% WWR, energy use more than doubles compared to windowless designs. Interestingly, north-facing façades with larger windows tend to outperform south-facing ones in terms of total energy use, benefiting from reduced direct solar radiation. Nonetheless, any significant increase in WWR—regardless of orientation—results in elevated energy consumption.

Overall, the results from Kandahar and Farah illustrate a progressive intensification of cooling demands from semi-arid to desert climates. This progression underscores the critical need to minimize glazing area and strategically select façade orientation in order to optimize energy performance in Afghanistan's hot regions.

4. Conclusions

This study was initiated in response to the pressing need for energy-efficient and climate-responsive design strategies in Afghanistan's residential building sector—an area that remains significantly under-researched despite increasing energy demands and escalating environmental concerns. In Afghanistan, where housing is largely informal, the electricity supply is unreliable, and the reliance on inefficient and polluting fuels remains widespread, the design of energy-efficient buildings is not merely a matter of sustainability but one of social and economic necessity. Given the absence of enforceable building codes and the limited adoption of passive design principles, this study aimed to provide a scientific basis for optimizing window configurations across the country's diverse climatic zones.

Using a simulation-based methodology through BEopt™, the research systematically evaluated the effects of varying WWR, glazing types, and building orientations on annual energy consumption for heating and cooling. The study focused on four representative cities, each exemplifying a distinct climatic region in Afghanistan. This approach enabled a comprehensive analysis of the interactions among critical passive design variables and generated a robust dataset that supports climate-specific design recommendations.

The findings revealed several important insights. Heating and cooling demand patterns exhibited a similar directional distribution across all regions, though the magnitude of energy savings or increase varied according to climatic conditions. Cooling energy consumption consistently increased with larger window areas, regardless of the city, façade orientation, or glazing performance. This suggests that in hot and cooling-dominated climates, providing windows does not contribute to energy savings and may, in fact, exacerbate the cooling load. Conversely, in cold regions, specific orientations—particularly those from ENE to WSW, which correspond to south-facing façades in the Northern Hemisphere—demonstrated the capacity to reduce heating energy consumption. These orientations maximize solar heat gain during winter and align with passive solar heating principles well-documented in international literature.

Furthermore, the study found that in cold-dominated cities such as Bamian and Ghazni, it is possible to reduce overall energy consumption significantly by optimizing window size and selecting appropriate glazing types for these orientations. In contrast, in cooling-dominant cities such as Kandahar and Farah, minimizing window size—regardless of glazing quality—is essential for reducing overall energy demand, as even high-performance glazing cannot offset the increased cooling load associated with larger windows. In cold climatic regions (Dsb and BSk), such as Bamian and Ghazni, WWRs of 40% - 70% offer significant energy-saving potential, with smaller WWRs recommended for single-glazed windows and higher WWRs for double- and triple-glazed windows. In hot regions, including Farah and Kandahar, window sizes should generally be limited to 10% - 15%, even when using double- or triple-glazing. These conclusions reaffirm the importance of designing windows in a climate- and orientation-sensitive manner and underscore that a one-size-fits-all approach is ineffective, particularly in a country with such diverse environmental conditions.

By generating empirical data that reflect real-world climatic diversity and building performance needs, this research contributes valuable insights for architects, engineers, and policymakers seeking to enhance energy efficiency in Afghanistan's residential sector. The results also support the development of climate-responsive guidelines and standards that can be adapted to local socio-economic conditions, construction practices, and energy constraints. In regions like Afghanistan, where affordability and accessibility are critical, the adoption of passive solar design strategies—particularly those related to window sizing and placement—offers a viable path toward more resilient and sustainable housing.

Looking forward, future research should expand upon this study by incorporating additional passive design elements such as insulation levels, shading devices, thermal mass, and building geometry. The inclusion of real-world occupancy behavior and empirical validation through field studies would further enhance the applicability and accuracy of simulation results. Ultimately, the integration of such findings into national building codes and urban planning frameworks is vital for achieving energy-conscious, affordable, and environmentally responsible development in Afghanistan and other similarly under-resourced regions.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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