

# Article

## Improving the Thermal Performance of Building Envelopes: An Approach to Enhancing the Building Energy Efficiency Code

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**Abstract:** Cities on the east Mediterranean coast, especially in Palestine, are struggling to move towards sustainability as they are vulnerable to climate change and lack natural resources, especially energy resources, and this situation is further aggravated by high energy prices. The problem is the building sector, which is the most challenging sector when it comes to cities' sustainability and, specifically, energy sustainability. In Palestine, this sector is the main consumer of energy but it lacks energy efficiency measures, such as up-to-date building energy codes. This study analyzed building thermal performance under different scenarios with a focus on building envelopes. We aimed to evaluate the benefits of introducing an updated building energy code—mainly addressing U-values for building envelopes—on future reductions in energy demand. We used a simulation tool (DesignBuilder) to evaluate typical existing building-envelope thermal and energy performances. Then, we undertook a comparison between the existing conditions and the proposed application of different scenarios, including the existing Palestinian building energy code and green building guidelines, the ASHRAE code for building envelopes, and the Jordanian building energy code, in order to introduce an updated building envelope energy code. The results showed that the current situation—building without applying any energy code or applying the existing Palestinian building energy code—is far from the high-energy performance that could be achieved by applying international or local green building codes. The use of thermal insulation could reduce the energy demand for heating by 83 to 43%, depending on the building type, climatic zone, and U-value. We recommend utilizing different U-values for building envelopes in different climatic zones to achieve high thermal performance. The results from this study have implications for construction industry professionals, local governments, and researchers seeking to establish high-energy-performance building envelopes.

**Keywords:** energy codes; climate change; energy efficiency; computer simulation; building envelope thermal performance; Palestine



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### 1. Introduction

It has been demonstrated that the building sector consumes a large amount of energy worldwide. As a result, strict energy efficiency regulations for new constructions and renovation of old buildings have been adopted in developed nations. Furthermore, greater amounts of energy are expected to be consumed in the building sector in the near future to meet growing living standards. All of this is occurring in the context of increasingly grim warnings about climate change and the depletion of fossil resources. Due to the environmental impact of using fossil fuels and the issue of their depletion, the topic of low-energy buildings has emerged as a major worry in Palestine [1,2].

In terms of energy, Palestine differs from other adjacent countries due to political uncertainty, poor economic conditions, a paucity of natural resources, and a high-density population [1]. Furthermore, all of Palestine's oil and 87% of its electricity are imported. For all of the aforementioned reasons, as well as the fact that buildings represent 43% of Palestinian energy consumption, it is critical to design structures that save energy and use diverse energy sources [1,3,4]. Residential buildings in Palestine have the highest energy consumption compared to other sectors, such as industry and transportation [4]. The Palestinian Energy and Natural Resources Authority (PENRA) has developed an energy-saving implementation plan, as the Palestinian Authority is making great efforts to reduce energy use. The purpose of this national action plan was to reduce energy usage by 384 GWh between 2012 and 2020. The construction industry consumes 363 GWh of total energy, accounting for approximately 94.5% [5,6]. Despite these initiatives, Palestinian construction regulations and standards are still deficient, and obtaining a building permit still does not require constructing insulation [5].

The amount of heat transmitted between the two air films on each side of a wall per unit area with a 1 °C temperature differential is known as the overall heat transfer coefficient (U-value). In the United States and the United Kingdom, it is measured in Btu/ft<sup>2</sup>·F, while Europe uses W/m<sup>2</sup>K [7].

An energy-efficient building code was produced by the Palestinian Ministry of Local Government (MLG) in 2004 [8]. In this code, the minimum requirements for the building envelope, which consists of exterior walls, windows, doors, ceilings, and floors—structural components that separate the interior environment of a building from the surrounding exterior environment—were outlined, but with similar values regardless of the different climatic conditions found in different zones in Palestine. Every climatic zone has a unique thermal environment and needs different considerations in a building energy code; this is a main weakness of the current Palestinian energy code. The Palestinian energy-efficient construction code has to be evaluated, and updated if necessary, to keep up with growing fuel prices and the effects of climate change.

Rodríguez-Soria et al. examined interior design temperatures, U-values, and compactness factors in the United States and many European countries (the United Kingdom, Germany, Spain, and France) [9]. Additionally, they looked at the passive house building standard, which the EU introduced as an illustration of a residential building that consumes almost zero energy (approximately zero-energy building). The demand response (DR) in detached residential buildings was studied by Alimohammadisagv et al. [10] to determine the most affordable option for a thermal energy storage system with a ground source heat pump in cold climate zones. Perry and Davidson [11] looked at economic models in order to enhance construction economics by changing Australia's building code. Echeverria et al. [12] investigated building energy efficiency in Spain from 2006 to 2016 in order to address problems posed by climate change. Manu et al. [13] investigated ways to improve people's thermal comfort by employing a newly proposed model known as the India Model for Adaptive Comfort (IMAC).

Moral et al. [14] investigated climate zoning in Extremadura (Spain) to quantify building thermal demand. They presented a mechanism for providing accurate climate zoning that is compliant with Spanish regulations on energy performance.

Nahlek et al. [15] studied energy modeling and building thermal performance. To determine how rapidly the interior air temperature changes when buildings are exposed to extreme heat, they developed an energy simulation model. In order to lower peak energy use, Tyagi et al. [16] investigated the energy efficiency of buildings using phase-change materials. There was good agreement between the experimental results and the theoretical values when they were compared. Using both finite element and experimental models, Assani et al. [17] assessed the influence of workmanship defects on building energy efficiency.

Khalfan [18] examined two comparable structures, one of which utilized the passive house standard and the other the typical measures used in Qatar. To compare the two constructions'

thermal efficiency and comfort levels, he employed modeling and on-site observations. In comparison to the standard model, he found that implementing the passive house criteria reduced water use, CO<sub>2</sub> emissions, and annual energy use by 50%. He also described the difficulties and restrictions associated with putting passive house principles into practice in Qatar.

Jaber and Ajib [19] looked at the ideal insulation thickness, building orientation, and window space in several Mediterranean residential constructions. They determined that they could reduce the amount of energy used annually by about 27.59% by choosing the right insulation thickness, building orientation, and window area.

According to Camur and Abdallah [1], the average U-value from the Palestinian energy-efficient construction code is the highest among all the nations they looked into. They also suggested that the U-value should maintain annual energy consumption in accordance with world standards. Alkhalidi et al. compared the total heat transfer coefficients in Jordanian building thermal insulation norms and other international building codes [7]. They suggested a new U-value that might reduce the demand for thermal energy by half. Alsayed and Tayeh [5] looked at the ideal thickness of insulating material for a number of Palestinian communities. They found that, for the two insulation types used—polystyrene and polyurethane—and the several Palestinian cities, the payback period varied between 0.9 and 1.6 years.

According to the International Energy Conservation Code, building envelope energy codes for residential uses focus on three main aspects: thermal insulation, fenestration, and air leakage [20]. Thermal insulation is the most important factor as it improves the thermal performance of the opaque envelope, which represents the largest part of the external envelope. Palestine faces a shortage of both natural and mineral resources. Moreover, Palestine's lack of conventional energy sources, such as oil and gas, as well as their high prices, which are on par with those in the most costly cities in the world, cause Palestinians great suffering [1,2]. Inspired by and due to this suffering, Palestinians have sought to overcome this dilemma by relying on alternative energy sources and reducing energy consumption as much as possible. There is no doubt that this trend in rationalizing energy consumption is in line with increasingly widespread global trend toward reductions in energy consumption. This global trend is gaining momentum day by day. It has emerged in response to the exacerbation of the great damage caused by high energy consumption and its obvious risks to human health and the environment alike, which we see most prominently in global warming, climate fluctuations, the widening of the ozone hole, acid rain in more than one region, and high fuel prices; the dangers of fossil fuels and the possibility of their depletion as a non-renewable resource; and, before and after this, the risks of various diseases caused by toxic and harmful gases released by the combustion of fuel [1,2]. Accurate building simulations can significantly influence predicted building energy consumption [21], and many studies have examined building thermal performance in different climate zones in order to achieve optimum building thermal performance [22], even looking at the feasibility of using photovoltaics to reduce construction costs and save energy [23]. Moreover, the increasing demand for and consumption of fossil fuels has led to rapid depletion along with rising greenhouse gas emissions and, therefore, global warming and climate change. The use of renewable energy resources and the rationalization of energy consumption are the most important means to reduce the consumption of fossil fuels [24,25].

This study aimed to estimate the potential energy savings and the improvements to thermal performance that would result from the implementation of future building energy codes focusing on thermal insulation in residential buildings in Palestine. This study provides suggestions for the development of U-value standards that could be used in the proposed update for Palestinian energy-efficient building codes. In the international context, a similar study compared the different building energy codes for countries in cold climates (Canada, Finland, Iceland, Norway, Sweden, China, and Russia) and, based on this comparison, proposed an optimization of building envelopes [26]. Another study compared Spain's and Morocco's building envelope energy codes and found that there is a need to update the building envelope energy regulations in Morocco [27]. In the Middle East, a study evaluated the effects of applying building envelope energy code regulations

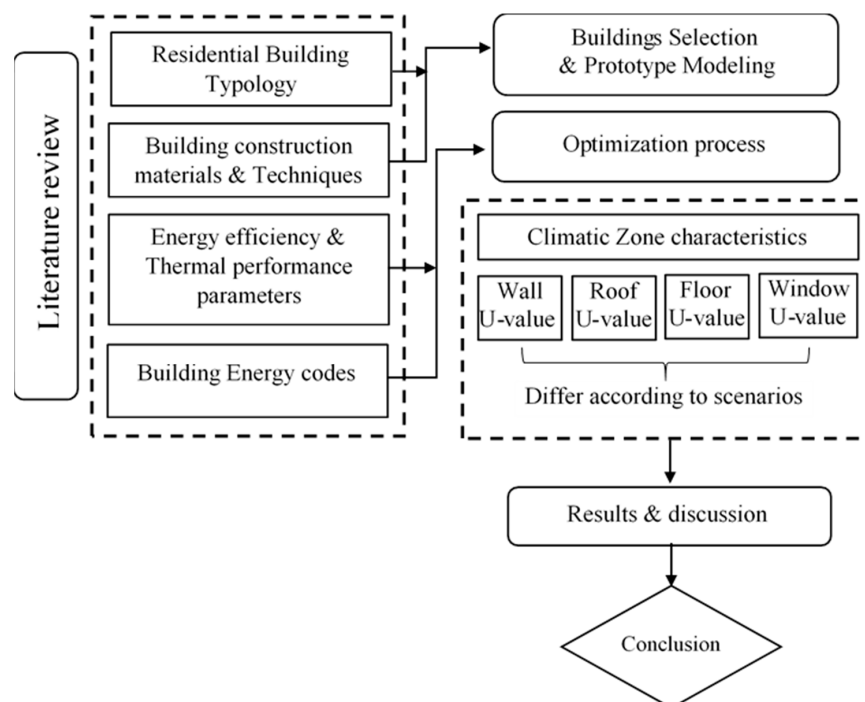
(sustainable building codes) from the Arabian Gulf Cooperation Council to residential buildings in Bahrain and found that the saving could reach up to 25% [28]. Furthermore, the continuous improvement of building envelope energy codes would have a positive effect on operation and maintenance costs [29]. The building energy code in Palestine needs to be addressed and evaluated in comparison to international, regional, and local standards to achieve energy efficiency goals [6].

It is important to compare the current construction of buildings (a base case scenario with no thermal insulation) with other available national and international building energy codes, such as the Palestinian building energy code [8], the Palestinian green building guidelines, international building codes (ASHRAE -90.1- 2019) [30], and the Jordanian building energy code [31], to evaluate the benefits for thermal performance and energy saving that would result from applying a new energy code for the Palestinian building sector.

This study is the first to assess various international building standards and contrast them with the Palestinian energy-efficient building code. This study aims to help develop a Palestinian energy-efficient building code by providing recommendations for building envelope U-values.

## 2. Materials and Methods

The general method proposed to estimate the potential energy savings and improvement to thermal performance resulting from the implementation of the future building energy codes in residential buildings in Palestine is shown in Figure 1. In the flowchart, the residential building typology, building construction materials and techniques, energy efficiency and thermal performance parameters, and building energy codes represent the input data. The residential building typology identifies the prevalent building typologies in Palestine. Building construction materials and techniques refer to the common construction materials and methods used in Palestinian residential buildings. The energy efficiency and thermal performance parameters refer to the most relevant thermal parameters for buildings, such as U-values. The building energy codes include different local, regional, and international energy building codes. From the combination of these inputs, representative building typologies were identified and used to characterize different energy scenarios in different climatic zones.



**Figure 1.** The research methodology flowchart.

### 2.1. Selection of Residential Building Type

In Palestine, residential buildings represent the majority of buildings and are responsible for the largest part of energy consumption and for more than 60% of electricity consumption [32]. For this reason, this study focused on the residential building sector. Residential buildings in Palestine consist of single houses, villas, and apartment buildings; according to a recent study, apartment buildings represent the majority of residential buildings in the West Bank and Gaza Strip [32].

These most commonly used residential building types were selected to build the simulation model to compare the benefits of the implementation of different building energy codes [32]. Two apartment building types were selected for the simulation: buildings with two apartments per floor and four apartments per floor, as seen in Figure 2. The reason for choosing these two different types of apartment buildings was to take into account the exposure to the outside environment, with the first type having the highest exposure and the second the lowest exposure, for the most commonly used apartment building types in Palestine.



**Figure 2.** Typical building types: two apartments per floor (type 1 on the left) and four apartments per floor (type 2 on the right).

### 2.2. Computer Thermal Simulation

The building performance computer simulation tool DesignBuilder was used to estimate the potential energy savings in residential buildings when applying different energy codes compared to base-case buildings representing the current situation in Palestine. The aim of the comparison was also to propose U-values for future building energy codes in Palestine. The simulation was undertaken for scenarios with different building types (two- and four-apartment building types), as explained below (see Table 1), and different climatic zones (see Figure 2).



**Table 1.** U-values for different standards and energy codes for three different climatic zones \*.

Scenario	U-Value for Walls (W/m <sup>2</sup> K)			U-Value for Windows (W/m <sup>2</sup> K)			U-Value for Roof (W/m <sup>2</sup> K)			U-Value for Floor (W/m <sup>2</sup> K)		
	Zone 1	Zone 4	Zone 6	Zone 1	Zone 4	Zone 6	Zone 1	Zone 4	Zone 6	Zone 1	Zone 4	Zone 6
Base case	2.44	2.44	2.44	3.61	3.61	3.16	2.32	2.32	2.32	1.723	1.723	1.723
Scenario 1	0.72	0.72	0.72	3.4	3.4	3.4	0.9	0.9	0.9	1.2	1.2	1.2
Scenario 2	0.5	0.5	0.5	2.46	2.46	2.46	0.39	0.39	0.39	0.46	0.46	0.46
Scenario 3	0.85	0.59	0.70	4.26	2.27	3.69	0.27	0.27	0.27	0.60	0.49	0.60
Scenario 4	0.57	0.57	0.57	3.1	3.1	3.1	0.55	0.55	0.55	0.8	0.8	0.8

\* When using the international building energy code, zone 1 corresponds to zone 2 of the ASHRAE climatic zones, zone 4 corresponds to zone 4 of the ASHRAE climatic zones, and zone 6 corresponds to zone 3 of the ASHRAE climatic zones.

In order to undertake the comparison and the sensitivity analysis, four different scenarios for the two building types and the three climatic zones were introduced.

Base case: The base case building with no thermal insulation; the building envelope is typical (stone, concrete, concrete block, and plaster) (see Table 2). No heating or cooling systems are used;

Scenario 1: Addition of thermal insulation to the base case according to the Palestinian building energy code and slight improvement in the windows' U-value;

Scenario 2: Addition of thermal insulation to the base case according to the Palestinian green building guidelines and improvement in the windows' U-value;

Scenario 3: Addition of thermal insulation to the base case according to the international building code (ASHRAE -90.1-2019) and definition of specific window U-values according to the corresponding climatic zone [23];

Scenario 4: Addition of thermal insulation to the base case according to the Jordanian building energy code and use of similar, new window U-values for the different climatic zones.

Based on the results from the above scenarios, thermal insulation values are proposed. These proposed thermal insulation values may be used for future Palestinian building energy codes.

The building envelope (external walls, floors, and roofs) was constructed based on the U-values explained in Table 1 above. The construction system and the construction materials used were based on onsite data and previous studies that addressed the most common construction techniques and materials [32–35]. Table 2 shows the physical and thermal properties of the building envelope.

**Table 2.** External wall, floor, and roof materials and thermo-physical parameters [34,35].

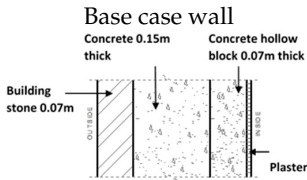
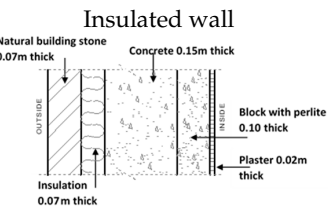
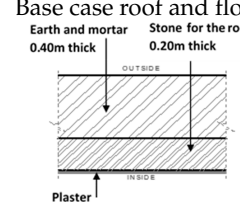
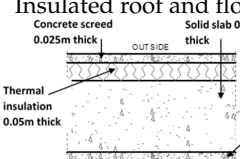
	Layers from Outside to Inside	Density (kg/m <sup>3</sup> )	Specific Heat (J/kg·K)	Conductivity (W/m·K)	Thickness (m)
	Natural stone	2350	920	1.5–2.6	0.07
	Reinforced concrete or backfill concrete (BC)	2300	670	0.8	0.15
	Hollow block	1200	840	1.35	0.1
	Cement plaster	900	1000	0.21	0.02
	Natural stone	2350	920	1.5–2.6	0.07
	Reinforced concrete or BC	2300	670	0.8	0.13
	Polystyrene foam	38	1130	0.033	0.05
	Hollow block	1200	840	1.35	0.1
	Cement plaster	900	1000	0.21	0.02

Table 2. Cont.

	Layers from Outside to Inside	Density (kg/m <sup>3</sup> )	Specific Heat (J/kg·K)	Conductivity (W/m·K)	Thickness (m)
<b>Base case roof and floor</b> 	Natural stone	2350	920	1.5–2.6	0.07
	Reinforced concrete or BC	2300	670	0.8	0.13
	Polystyrene foam	38	1130	0.033	0.05
	Hollow block	1200	840	1.35	0.1
	Cement plaster	900	1000	0.21	0.02
<b>Insulated roof and floor</b> 	Natural stone	2350	920	1.5–2.6	0.07
	Reinforced concrete or BC	2300	670	0.8	0.13
	Polystyrene foam	38	1130	0.033	0.05
	Hollow block	1200	840	1.35	0.1
	Cement plaster	900	1000	0.21	0.02

Palestinian territories have seven climatic zones, as can be seen in Figure 3. For simplicity's sake, only the three climatic zones in the West Bank and Gaza Strip were selected for the simulation for the abovementioned scenarios. The reasons for selecting these three climatic zones were because they have the largest areas and the highest population densities. These climatic zones have the largest cities in Palestine and the highest numbers of existing buildings, as well as holding the potential for the highest growth in future residential building construction. The other four climatic zones were not considered in this study because they are either non-populated areas or have climatic conditions that are close to the selected zones. Future studies can expand the results from this study to include all the climatic zones in Palestine.

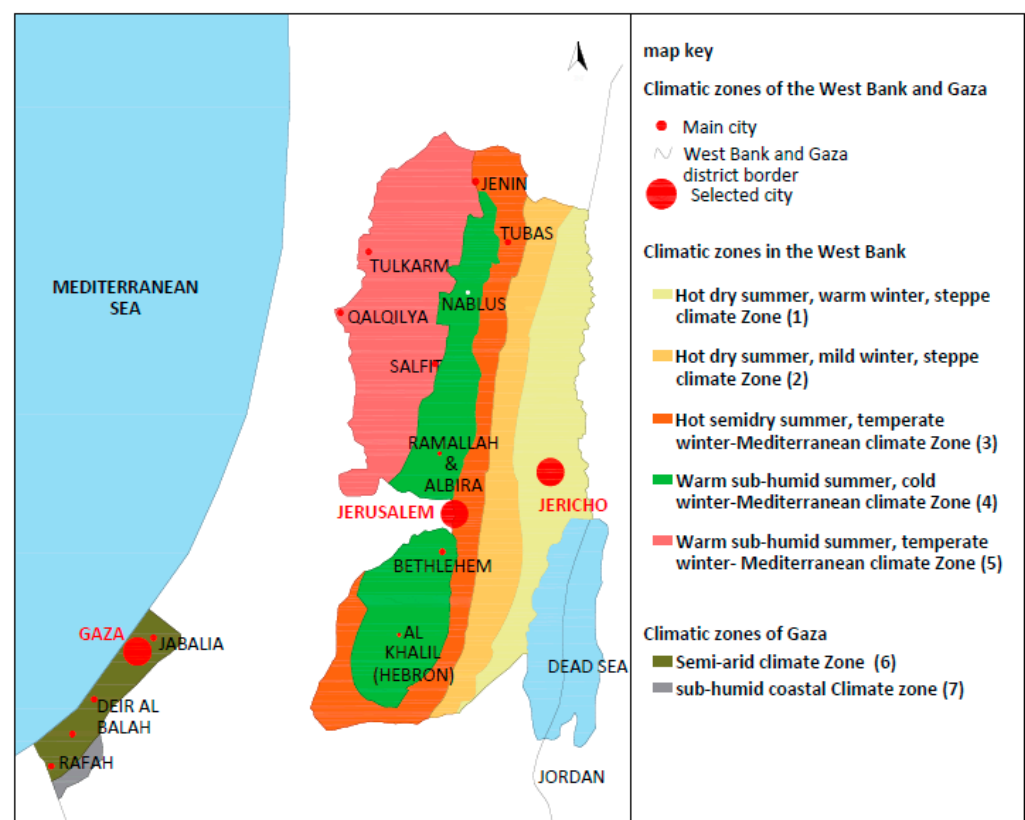
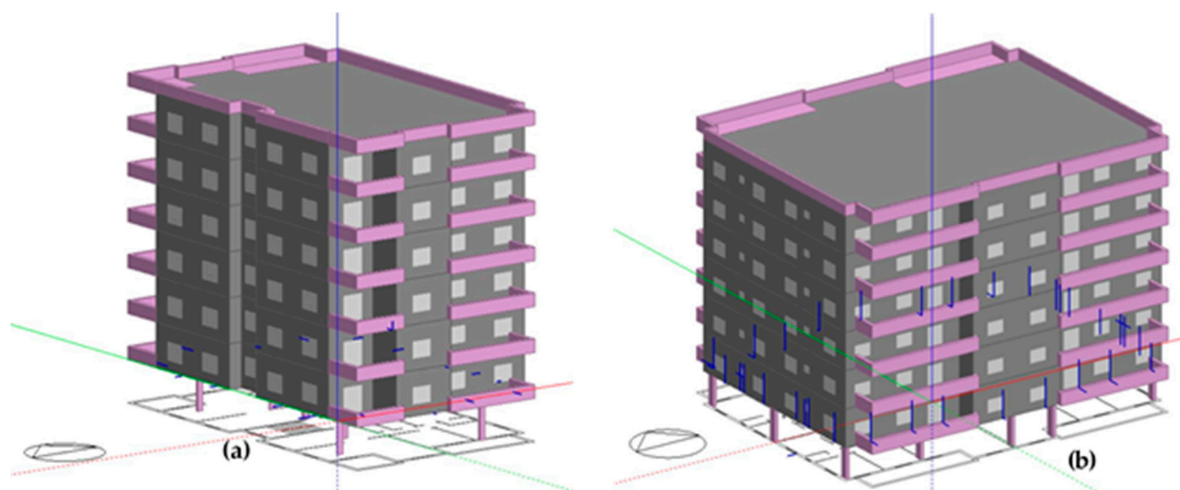
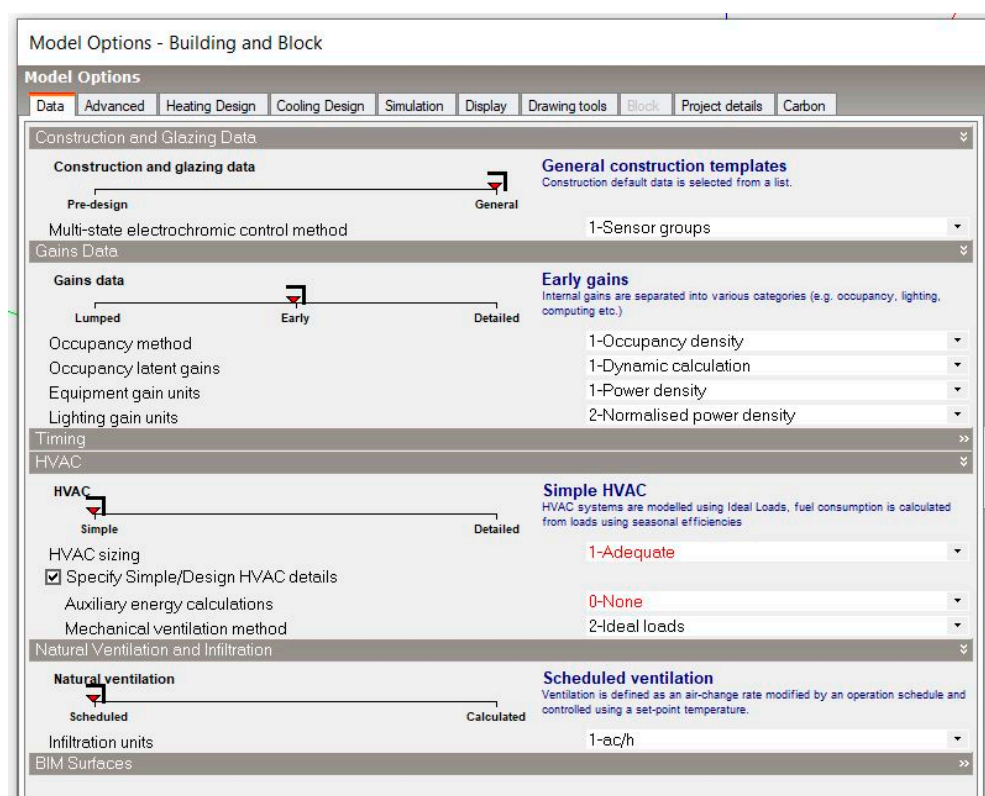


Figure 3. Climatic zones in Palestinian territories and the three climatic zones selected [33].

In order to explore the various possibilities for apartment buildings, the two pre-selected apartment building types were modeled and simulated using DesignBuilder software in accordance with the aforementioned scenarios and climatic conditions. The DesignBuilder models for the selected building types are shown in Figure 4. Figure 5 shows some of the model options defined for the simulation in DesignBuilder software. Moreover, the heating and cooling loads are illustrated for three floors: the first floor, which is exposed to the open parking floor on the ground floor; the intermediate apartment floor, where there is no exposure to the outdoors via the floor or roof; and the top floor apartment, where the roof is exposed to the outdoor environment. Table 3 shows the simulation input parameters.



**Figure 4.** DesignBuilder modeling: (a) two-apartment building, (b) four-apartment building, the pink color represents the balconies and parapets, and grey color represent the external envelope.



**Figure 5.** Some of model options defined for the DesignBuilder simulation.



**Table 3.** DesignBuilder simulation parameters.

Parameters		Value
Construction	Envelope U-Values (W/m <sup>2</sup> K)	According to Scenario
Activity floor area (m <sup>2</sup> )	Occupancy density/apartment (people/m <sup>2</sup> )	0.039
	Two-apartment type	345
	Four-apartment type	635
	Window height (m)	1.25
	Window width (m)	1.6
Openings	Window frame type	Aluminum—no thermal breakers
	Window U-value (W/m <sup>2</sup> K)	According to scenario
	Shading	N/A
	Natural ventilation	Inactive
	Mechanical ventilation	Active
Environmental control	HVAC system	Active
	Heating system	Natural gas
	Heating set point (°C)	21
	Cooling system	Electricity from the grid
	Cooling set point (°C)	25
Lighting	Air infiltration (ac/h)	0.5
	Normalized power density (W/m <sup>2</sup> -100 lux)	0.25

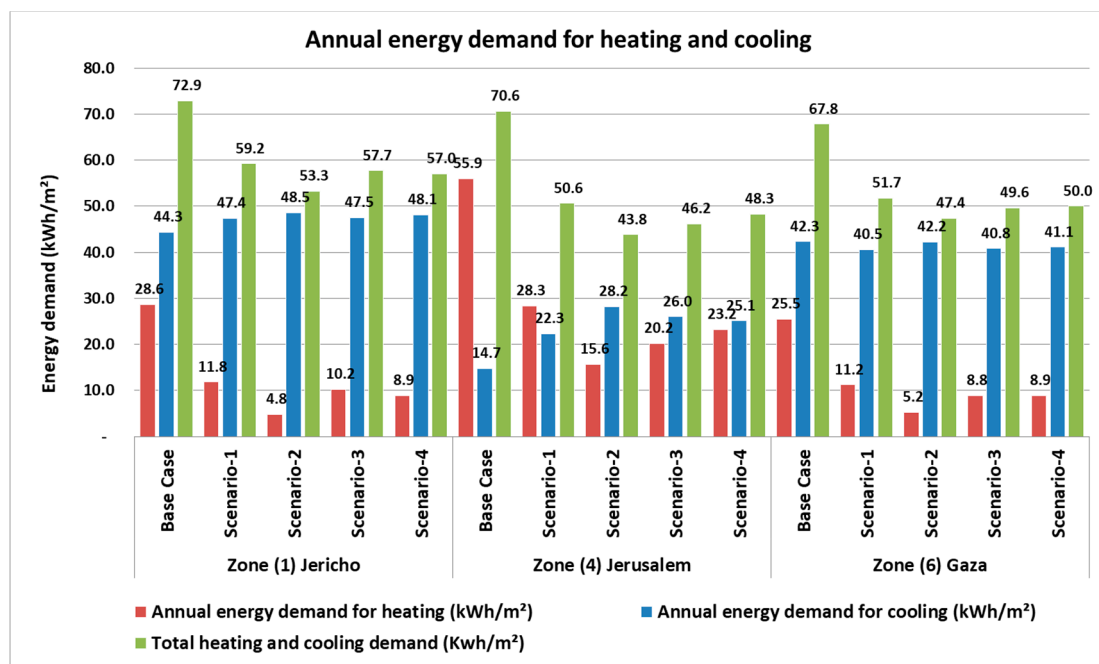
The validation process in this research was based on analytical references. By comparing the annual average energy load for one apartment achieved in the test model (4940 kWh) with the results obtained in several previous studies (5000 kWh) [36,37], it was found that the divergence was 1.2%. The difference between the previous and modeled results was less than 5% and, thus, it can be concluded that the model was validated [38].

### 3. Results and Discussion

#### 3.1. Residential Building with Two Apartments per Floor (Type 1)

The results from the simulation showed that adding thermal insulation according to different building codes and regulations had a positive impact in all climatic zones by reducing the energy demand for heating compared to the base case scenario where there was no application of building energy codes related to thermal insulation. For all climate zones, regardless of the floor (first, intermediate, or top floor), the base case had the highest energy demand for heating, and the best scenario was scenario 2, which was addition of thermal insulation to the base case according to the Palestinian green building guidelines. The worst scenario was scenario 1, which was addition of thermal insulation to the base case according to the Palestinian building energy code.

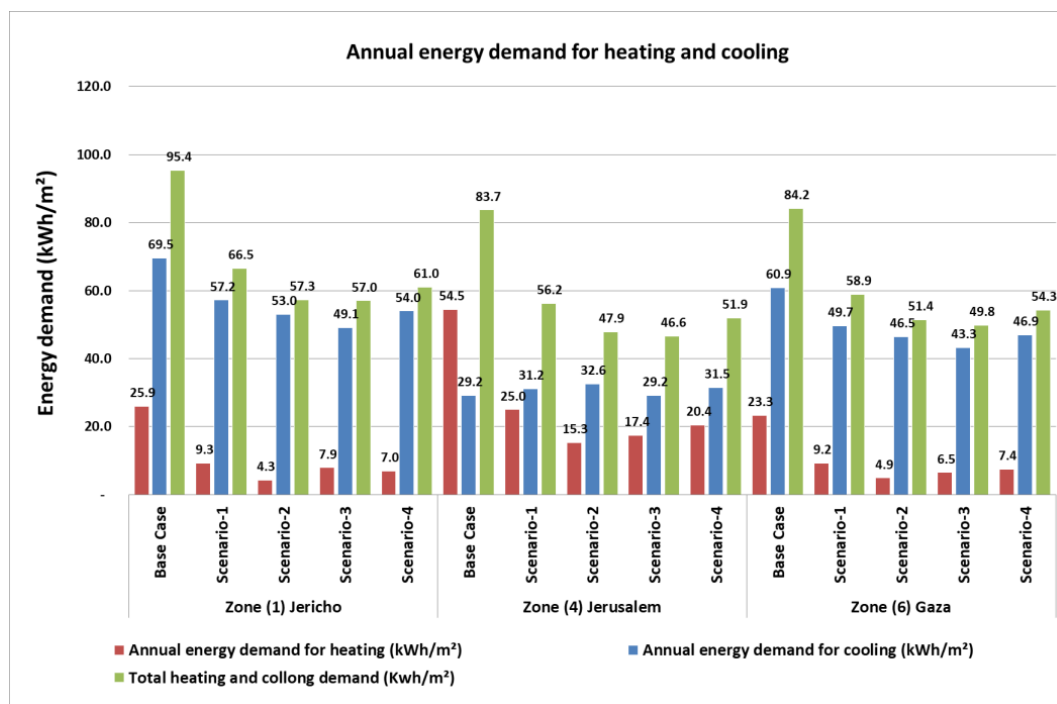
When looking at the results for the first floor (the floor of the apartment is exposed to the open parking lot below), the results showed that, in climatic zone 1, the reductions in the energy demand for heating with the different thermal insulation scenarios compared to the base case were 83% for scenario 2, followed by 69%, 64%, and 59% for scenarios 4, 3, and 1, respectively. In climatic zone 4, the reductions in the heating energy demand for different thermal insulation scenarios compared to the base case were 72% for scenario 2, followed by 64%, 59%, and 49% for scenarios 3, 4, and 1, respectively. In climatic zone 6, the reductions in the energy demand for heating for different thermal insulation scenarios compared to the base case were 80% for scenario 2, followed by 65% for scenarios 3 and 4 and 56% for scenario 1, as seen in Figure 6.



**Figure 6.** Comparison of annual heating and cooling energy demand for different scenarios and climatic zones for building type 1—first floor.

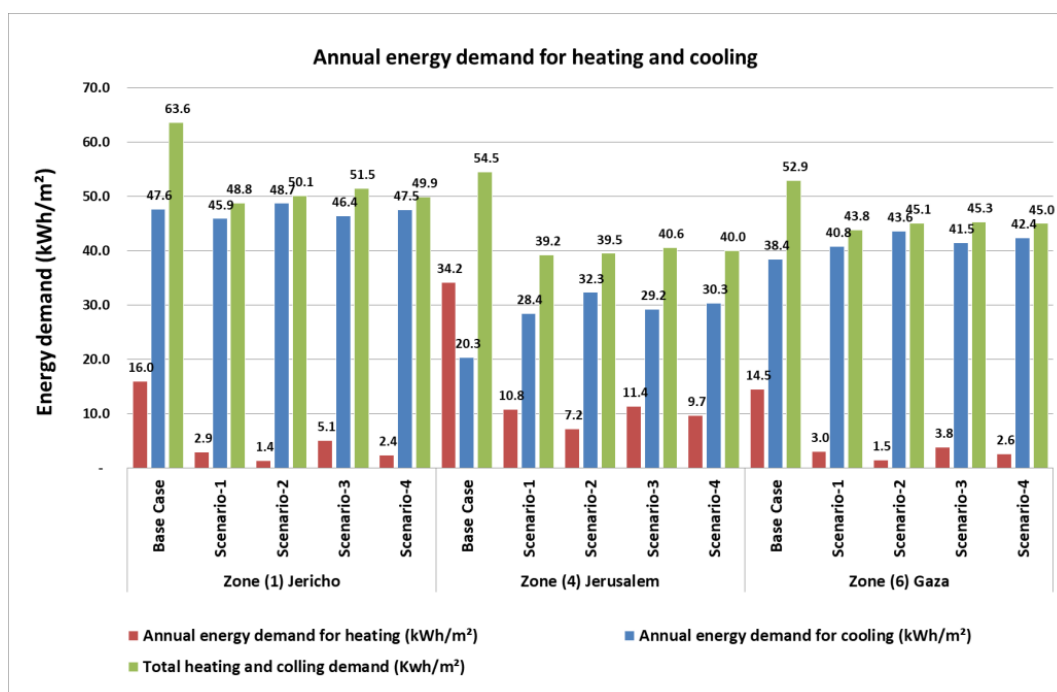
The results above show that the greatest reduction in energy demand would occur in climatic zone 4, which has a hot, dry summer and cold winter. This was expected, as this zone has the highest energy demand for heating. However, the percentages of energy demand reduction were the highest in zone 1, followed by zone 6 and zone 4, respectively. When considering the energy load for cooling and the total energy demand for heating and cooling, the results showed that the thermal insulation had a negative or no impact on the total energy load, especially for zones 1 and 6, which are characterized by very hot and dry summers, as well as a warm winter in zone 1 and hot summer and mild winter in zone 6. This was expected, as the simulation model did not take into account the use of passive strategies for cooling, such as the use of natural ventilation, which is especially relevant for zone 4, where it is very efficient in summer, and zones 1 and 6, which have high summer temperatures.

For the top floor plan with an exposed roof, the results were very similar to the first floor where the apartments have flooring exposed to the unenclosed parking lot on the ground floor below. The reductions in heating energy demand from the application of energy codes in different scenarios compared to the base case ranged between 83% for scenario 2 in zone 1 and 54% for scenario 1 in climatic zone 4. For all climatic zones, scenario 2 resulted in the highest reduction in heating energy demand. Similarly to the first floor, the highest reduction in the energy demand for heating was in climatic zone 4, and the highest demand reduction percentages were in zone 1, followed by zones 6 and 4, respectively, as seen in Figure 7.



**Figure 7.** Comparison of annual energy demand for heating and cooling for different scenarios and climatic zones for building type 1—top floor.

For the intermediate floor, the energy demand for heating was lower compared to the first and top floors. The reductions in heating energy demand when applying energy codes with the different scenarios compared to the base case were high, ranging between 91% for scenario 2 in zone 1 and 68% for scenario 3 in climatic zone 4. Again, for all climatic zones, scenario 2 resulted in the highest reduction in heating energy demand, as seen in Figure 8.



**Figure 8.** Comparison of annual energy demand for heating and cooling for different scenarios and climatic zones for building type 1—intermediate floor.

### 3.2. Residential Building with Four Apartments per Floor (Type 2)

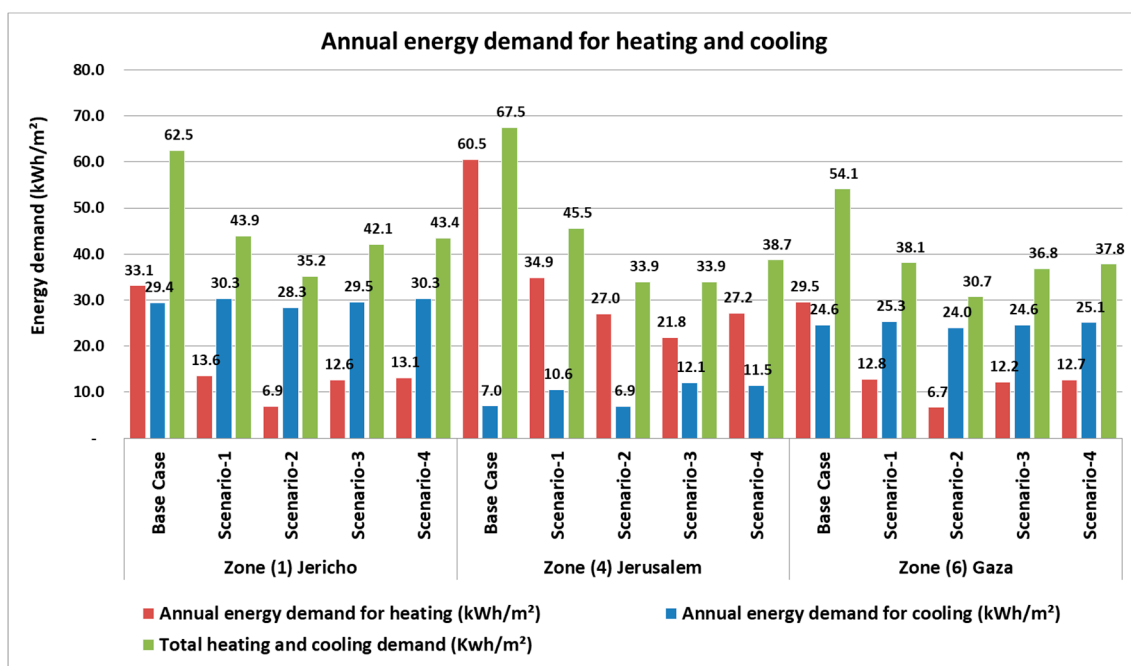
The results for the second building type showed positive effects from adding thermal insulation that were similar to those for the first building type. The results showed the same trends for the reductions in energy demand for the different climatic zones and scenarios when applying the different codes. The reductions in energy demand were high when comparing the base case scenario with the other scenarios in which building energy codes were applied, as seen in Figures 9–11.

For climatic zone 1, the highest energy demand reductions for the first, top, and intermediate floors were 79%, 75%, and 72%, respectively, in scenario 2. Then, there were reductions of 62% and 66% for the first and top floors in scenario 3 and 69% for the intermediate floor in scenario 4. There were reductions of 60% and 63% for the first and top floors in scenario 4, and 69% for the intermediate floor in scenario 1. The lowest energy demand reductions were 59% and 54% for the first and top floors in scenario 1 and 57% for the intermediate floor in scenario 3.

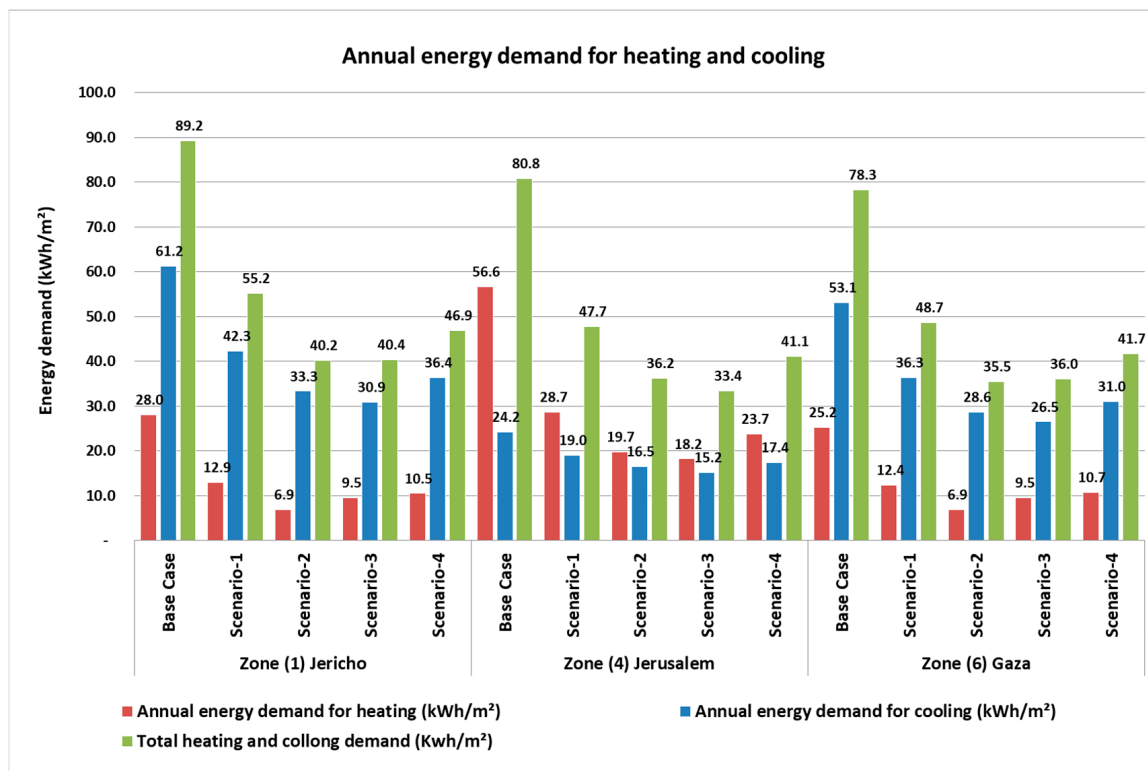
For climatic zone 4, the highest energy demand reductions for the first, top, and intermediate floors were 63%, 67%, and 64%, respectively, in scenario 3. These were followed by 55%, 65%, and 60%, respectively, in scenario 2 and 55%, 58%, and 60%, respectively, in scenario 4. The lowest energy demand reductions were 43%, 49%, and 59%, respectively, in scenario 1.

For climatic zone 6, the highest energy demand reductions were 77%, 73%, and 82%, respectively, in scenario 2. These were followed by 59% and 62% for the first and top floors in scenario 3 and 67% for the intermediate floor for scenario 4. There were reductions of 57%, 58%, and 67%, respectively, in scenario 4, and the lowest energy demand reductions were 56% and 51% for the first and top floors in scenario 1 and 54% for the intermediate floor in scenario 3.

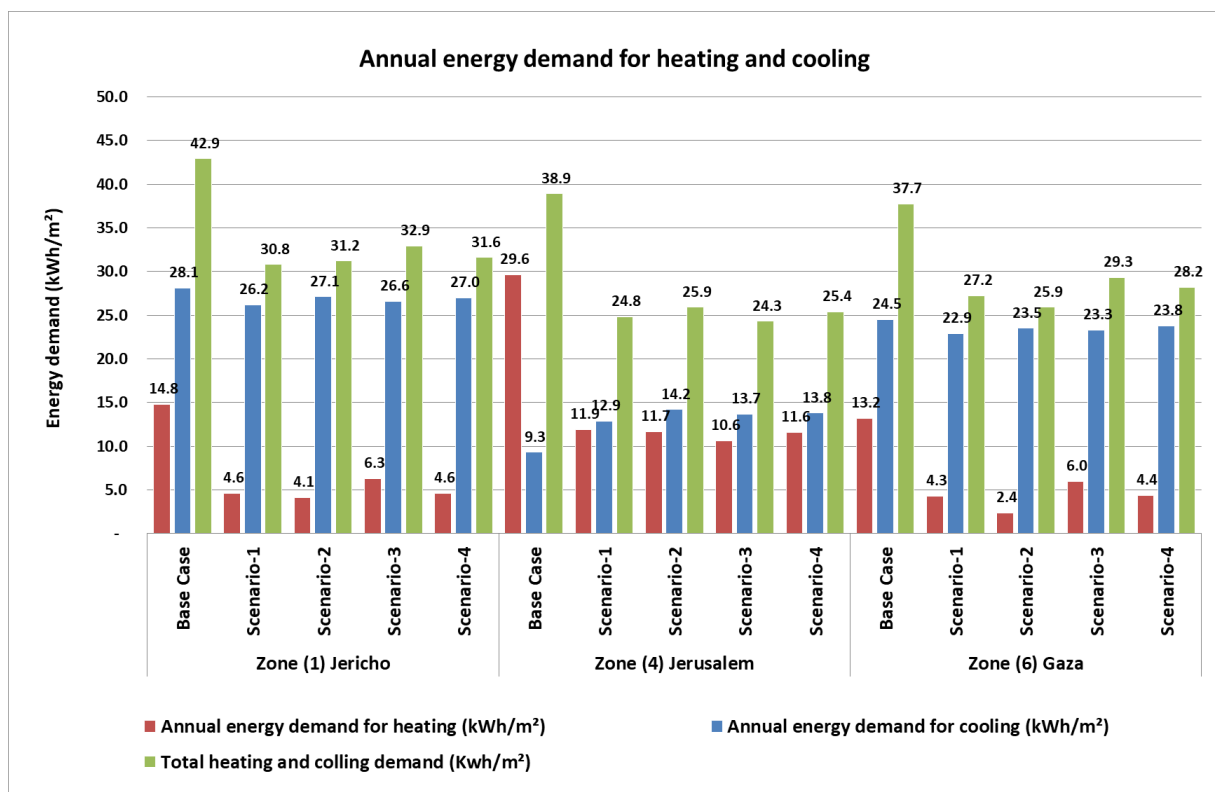
As this study aimed to evaluate the effects of applying building energy codes with a focus on thermal insulation, the analysis below targets the reduction in the energy demand for heating only when applying different codes. The energy demand reduction for cooling was excluded here because the code for the cooling design should include other variables, such as shading, natural ventilation, thermal mass, and infiltration, which were not within the scope of this research.



**Figure 9.** Comparison of annual heating and cooling energy demand for different scenarios and climatic zones for building type 2—first floor.



**Figure 10.** Comparison of annual heating and cooling energy demand for different scenarios and climatic zones for building type 2—top floor.



**Figure 11.** Comparison of annual heating and cooling energy demand for different scenarios and climatic zones for building type 2—intermediate floor.



Figures 12–14 show the energy demand for heating in the different climatic zones and thermal insulation scenarios for the first, top, and intermediate floors, respectively. These results also show the difference between building types one and two. In climatic zones 1 and 6 (characterized by hot summers and moderate or warm winters), the best scenario was scenario 2, followed by scenarios 3, 4, and 1, except for the intermediate floor, for which scenario 2 was the best, followed by scenarios 4, 1, and 3.

In climatic zone 4, scenario 3 showed the best results for the energy demand reduction, followed by scenarios 2, 4, and 1.

The difference between building types 1 and 2 lies in the lower energy demand for building type 1 compared to building type 2 in all climatic zones and scenarios, except for the intermediate floor in the base case scenario, for which building type 1 had a higher energy demand. This can be explained by the fact that building type 1 has more exposure to solar radiation, which increases thermal gain in the winter and reduces the energy demand, especially when thermal insulation has been installed in the exposed external walls.

The results from this study are in line with other recent studies on the optimization of thermal insulation for buildings in Palestine. These results demonstrate the importance of improving building envelope thermal performance and show similar significant energy demand reductions and other benefits from such optimization [1,2,22,24]. Those studies also recommend an optimization approach to improve the future building energy code, which is one of the most important aims of this study.

This study illustrated the influence of different energy building codes on annual energy demand, with a focus on heating energy demand for two representative apartment building types in the three main climatic zones in Palestine. A simulation-based study and sensitivity analysis were used to determine the best scenarios and most efficient U-values for building envelopes in the different climatic zones. U-values for a new building energy code in Palestine were recommended.

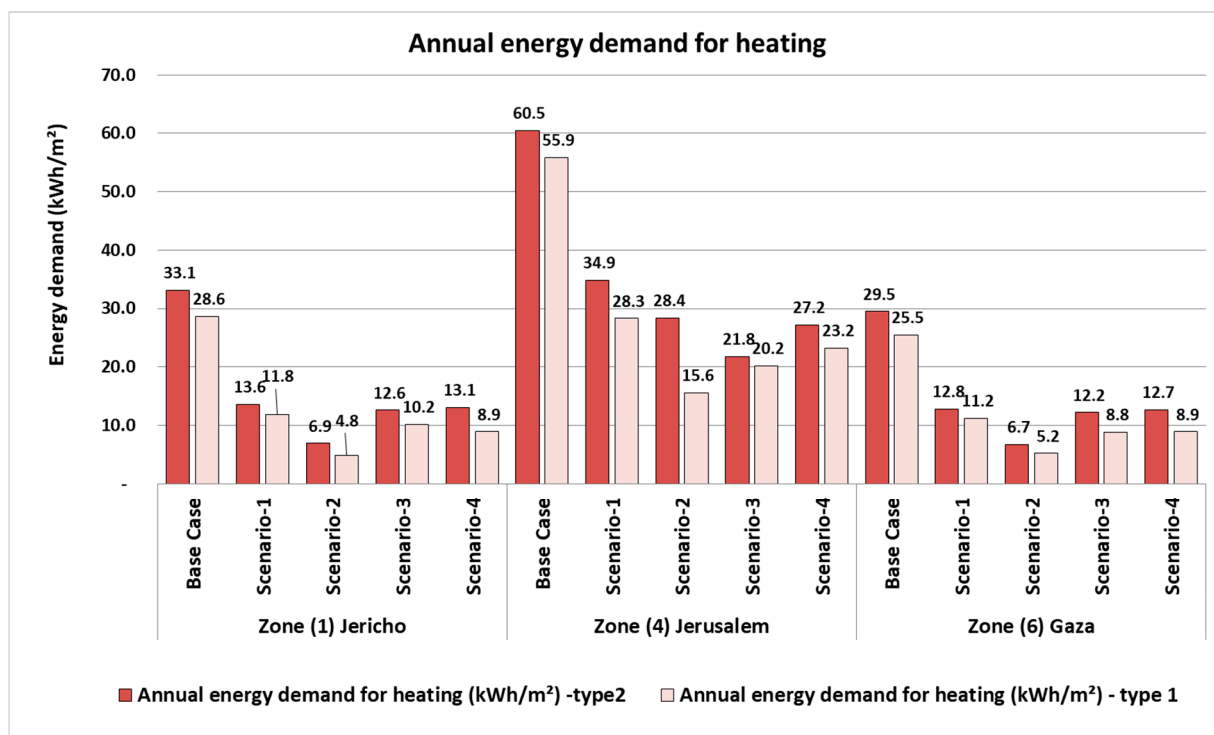


Figure 12. Comparison of heating energy demand for building types 1 and 2 in the different zones and scenarios for the first floor.

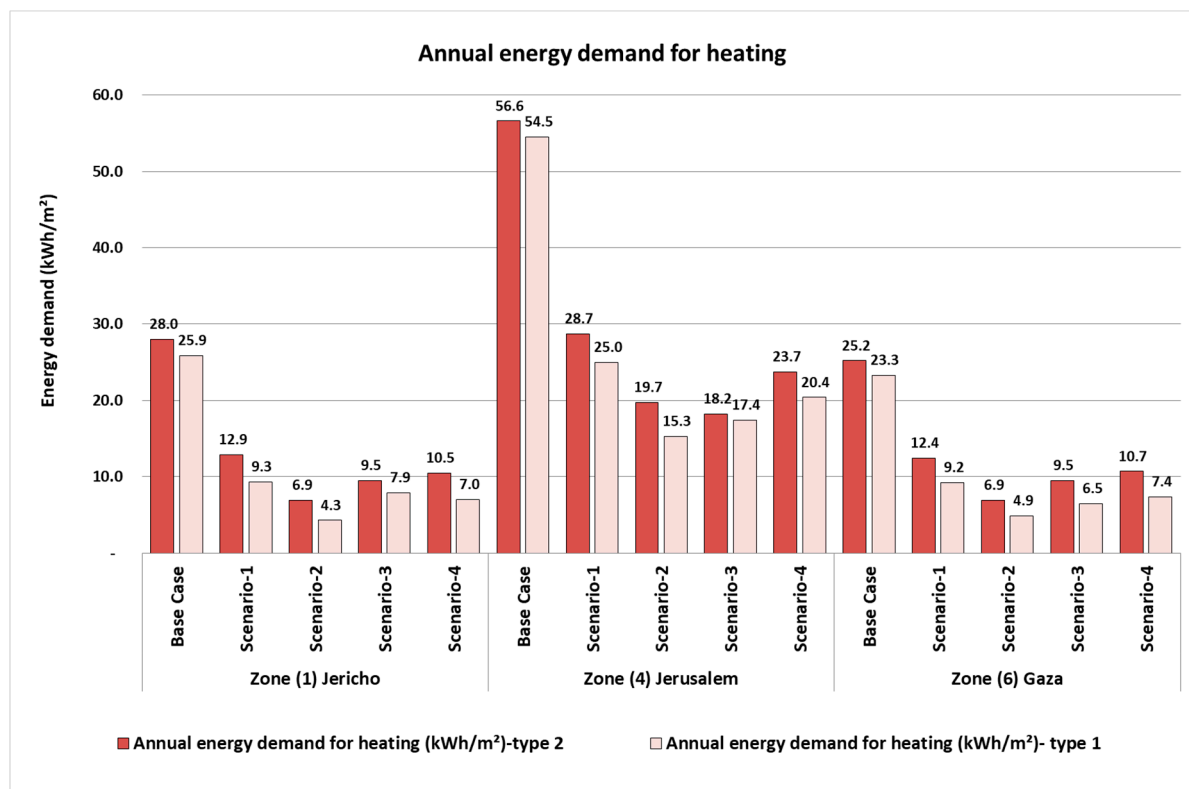


Figure 13. Comparison of heating energy demand for building types 1 and 2 in the different zones and scenarios for the top floor.

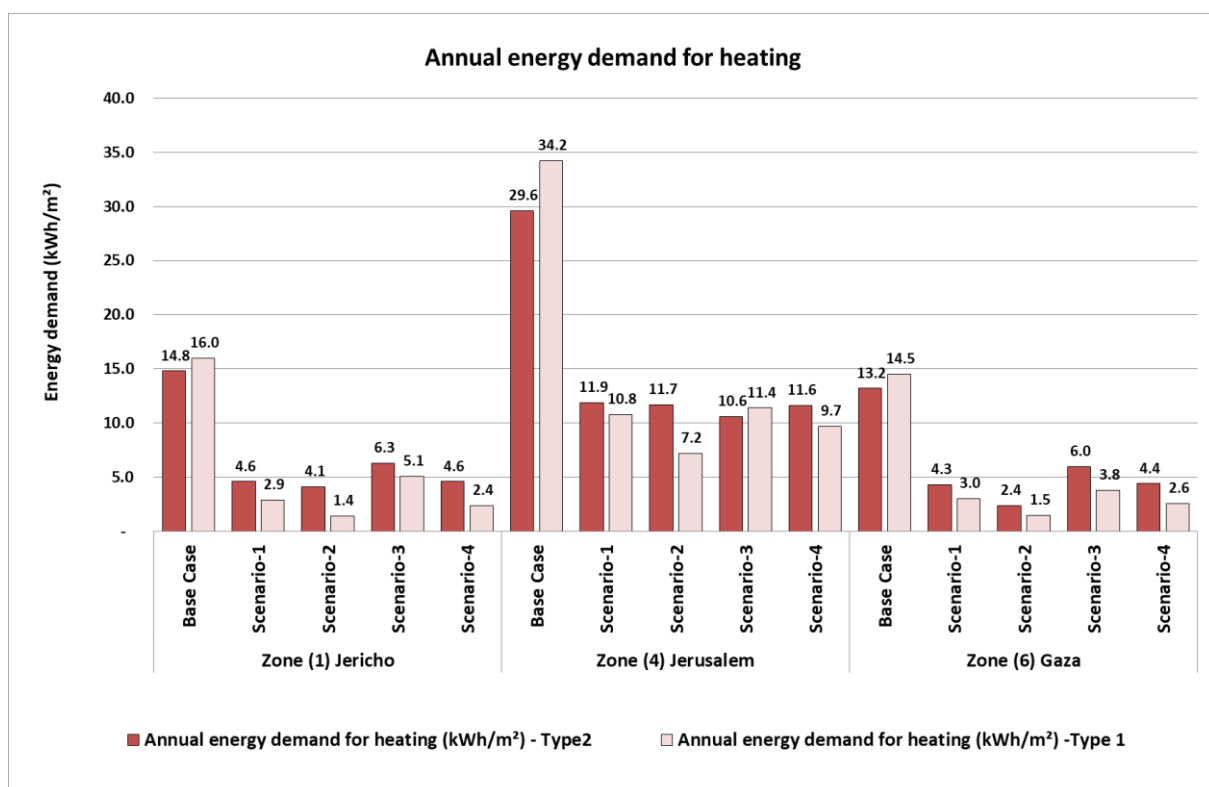


Figure 14. Comparison of heating energy demand for building types 1 and 2 in the different zones and scenarios for the intermediate floor.

The different building types showed different reductions in energy demand when adding thermal insulation. Building type 1 (two apartments per floor) had the greatest reduction when scenario 2 (Palestinian green building guidelines) was applied and building type 2 (four apartments per floor area) had the greatest reduction when scenario 3 (ASHRAE standards) was applied.

Regarding the U-values for the building envelope (walls, windows, floors, and roofs) of residential buildings in Palestine, we recommend the use of U-values close to the ASHRAE standards and the Jordanian building energy code for the climatic zones characterized by hot summers and cold winters. For the climatic zones characterized by hot summers and mild and warm winters, we recommend the use of U-values close to the green building guidelines and the Jordanian building energy code. Based on the results from the study, Table 4 shows the values recommended for the optimization of a future building energy code in Palestine.

**Table 4.** Proposed U-values for building envelopes for different climatic zones in Palestine.

Scenario	U-Value for Walls (W/m <sup>2</sup> K)			U-Value for Windows (W/m <sup>2</sup> K)			U-Value for Roofs (W/m <sup>2</sup> K)			U-Value for Floors (W/m <sup>2</sup> K)		
	Zone 1	Zone 4	Zone 6	Zone 1	Zone 4	Zone 6	Zone 1	Zone 4	Zone 6	Zone 1	Zone 4	Zone 6
Uninsulated buildings	2.44	2.44	2.44	3.61	3.61	3.16	2.32	2.32	2.32	1.723	1.723	1.723
Current building energy code	0.72	0.72	0.72	3.4	3.4	3.4	0.9	0.9	0.9	1.2	1.2	1.2
Proposed U-values	0.57	0.59	0.57	3.1	2.25	3.1	0.39	0.27	0.39	0.6	0.49	0.6

#### 4. Conclusions

The great reduction in energy demand resulting from thermal insulation—and especially the reduction in the energy demand for heating—was confirmed. Among the different climatic zones and building types, this reduction reached up to 83% for the best scenario and 43% for the worst-case scenario in comparison to the absence of thermal insulation in the base case scenario. The current building energy code in Palestine is the worst scenario compared to the other local, regional, and international building energy codes. This reveals the importance of introducing a new and up-to-date energy-efficient building code for Palestine, as the region is facing a rising energy demand and the effects of climate change.

Different building types need different approaches when adding thermal insulation. These differences need to be taken into account in the future energy code for Palestine.

In the current situation, regardless of the climatic zones' characteristics, the local and Jordanian energy-efficient building codes provide the same U-values for the walls, roofs, and floors in all climatic zones. However, this study shows that different climatic zones may need different U-values. Climatic zones 1 and 6, which are characterized by hot summers and mild winters, require different U-values from zone 4, which is characterized by hot summers and cold winters.

Moreover, the highest percentage reductions in energy demand for heating were for climatic zones 1 and 6, which are characterized by low total energy demand for heating due to the fact that they have mild and warm winters. The percentage energy reduction was lower for climatic zone 4; however, the total reduction was significantly greater due to the fact that this climatic zone is characterized by cold winters. Taking this into consideration, the future energy efficiency code (especially the U-values) should be strictly applied in this zone; however, in zones 1 and 6, the U-values can be higher.

Based on the comparison and evaluation of different scenarios for building envelope U values, we recommend an update (proposed U-values) that can be adopted in future building energy codes in Palestine. The implications of the study are of great importance for local government ministries and municipalities in Palestine, as these parties are pushing

towards the adoption of energy efficiency measures to adapt to rising energy demands and the effects of climate change.

Finally, it should be recognized the results of this study are limited to certain building types with certain building materials (the materials typically used in the residential construction sector in Palestine), and the study focused on the heating load rather than the total load. The cooling load was calculated; however, strategies to reduce cooling load (i.e., the use of natural ventilation and thermal mass) were not addressed, as the focus of the study was the analysis of the effects of thermal insulation on heating load. These limitations can be addressed in future studies with other building types and the cooling load taken into account. Future studies can also address the influence of different building envelope components on overall energy demand and the optimization of U-values based on envelope material modifications.

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## Abbreviations

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
DR	Demand Response
EU	European Union
IMAC	India Model for Adaptive Comfort
MLG	Ministry of Local Government
U-value	Overall heat transfer coefficient

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