

## Article

# Towards Sustainable Energy Retrofitting, a Simulation for Potential Energy Use Reduction in Residential Buildings in Palestine

Sameh Monna <sup>1</sup>, Adel Juaidi <sup>2,\*</sup>, Ramez Abdallah <sup>2</sup>, Aiman Albatayneh <sup>3</sup>, Patrick Dutournie <sup>4,5</sup> and Mejdi Jeguirim <sup>4,5,\*</sup>

- <sup>1</sup> Architectural Engineering Department, An-Najah National University, P.O. Box 7, Nablus 00970, Palestine; samehmona@najah.edu
- <sup>2</sup> Mechanical & Mechatronics Engineering Department, An-Najah National University, P.O. Box 7, Nablus 00970, Palestine; ramezkhaldi@najah.edu
- <sup>3</sup> School of Natural Resources Engineering and Management, German Jordanian University, P.O. Box 35247, Amman 11180, Jordan; Aiman.Albatayneh@gju.edu.jo
- <sup>4</sup> CNRS, IS2M UMR 7361, Université de Haute-Alsace, 68100 Mulhouse, France; patrick.dutournie@uha.fr
- <sup>5</sup> CNRS, IS2M UMR 7361, Université de Strasbourg, 67000 Strasbourg, France
- \* Correspondence: adel@najah.edu (A.J.); mejdi.jeguirim@uha.fr (M.J.)

**Abstract:** Since buildings are one of the major contributors to global warming, efforts should be intensified to make them more energy-efficient, particularly existing buildings. This research intends to analyze the energy savings from a suggested retrofitting program using energy simulation for typical existing residential buildings. For the assessment of the energy retrofitting program using computer simulation, the most commonly utilized residential building types were selected. The energy consumption of those selected residential buildings was assessed, and a baseline for evaluating energy retrofitting was established. Three levels of retrofitting programs were implemented. These levels were ordered by cost, with the first level being the least costly and the third level is the most expensive. The simulation models were created for two different types of buildings in three different climatic zones in Palestine. The findings suggest that water heating, space heating, space cooling, and electric lighting are the highest energy consumers in ordinary houses. Level one measures resulted in a 19–24 percent decrease in energy consumption due to reduced heating and cooling loads. The use of a combination of levels one and two resulted in a decrease of energy consumption for heating, cooling, and lighting by 50–57%. The use of the three levels resulted in a decrease of 71–80% in total energy usage for heating, cooling, lighting, water heating, and air conditioning.

**Keywords:** residential buildings; energy retrofitting; performance simulation; Palestine; design builder



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## 1. Introduction

Green energy refers to renewable energy sources that are regarded to be environmentally friendly. These energy sources aid in mitigating the consequences of global warming, a rise in the Earth's average temperature caused by fossil fuel emissions [1–3]. The construction industry is well-known as one of the world's largest energy users [4]. Buildings' final energy consumption rose from 118 EJ in 2010 to about 128 EJ in 2019. Their CO<sub>2</sub> emissions increased by more than 10 GtCO<sub>2</sub> in 2019, accounting for 30% and 28% of global totals, respectively (IEA, 2020) [5].

Residential energy retrofitting has been recognized as an effective way to encourage energy efficiency and carbon reduction while also improving people's life quality [6]. Buildings account for 16–50% of overall energy demand worldwide [7], while the amount is 40% in Europe [8,9]. Existing building renovations provide outstanding ways to reduce electricity consumption and therefore greenhouse gas emissions [4]. After manufacturing and transportation, the construction sector accounts for 40% of overall final energy

demand [10,11], putting it in the third position [12]. Furthermore, energy consumption in the urban world is projected to increase by 34% in the next 20 years, at an annual rate of 1.5% [12]. In 2030, the residential sector will account for 67% of total energy demand, while the non-domestic sector will account for 33 percent [13]. In most countries, buildings have been the primary energy consumers for cooling and heating [14]. The building industry, especially current residential buildings, is the largest energy user [15]. The consumption is mainly caused by a variety of operations, including cooling, heating, ventilation, lighting, and operating electrical equipment [15]. As a result, efforts should be focused on optimizing building efficiency in order to reduce energy usage [15].

Adding thermal insulation, solar shielding, reducing thermal load, updating old inefficient appliances, and adding green energy technologies are only a few of the energy-saving steps that can be applied by energy retrofitting programs [16–18]. Improving the energy efficiency of buildings, especially those that are already in use, is critical for combating climate change [19]. The primary cause of these trends is the rising of living conditions and comfort expectations [20]. Improving building energy quality should also be a priority in the fight against climate change and global warming [21,22]. In recent years, increasing the energy efficiency of existing buildings has been an important concern [23]. In order to achieve cost-effective solutions in the residential building sector, energy retrofitting methods should be defined on the basis of regulations [23].

Residential energy retrofitting is a strategy for lowering global energy demand [6]. Building energy usage has surpassed transportation as the primary source of global energy demand and CO<sub>2</sub> pollution [6,24–32]. Retrofitting not only reduces energy consumption and costs, but it also improves indoor air quality and decreases unwanted noise, improving the business value [33]. Budget, comfort criteria, and stable economic benefit are all considerations that influence the introduction of energy retrofit initiatives [33].

### *1.1. Energy Sector in Palestine*

The Palestinian energy sector is confronted with a number of challenges, including energy insecurity, high fuel prices, rising demand, and a lack of sustainable consumption. Energy efficiency may improve the living conditions of Palestinian households and increase the community's resilience [34]. During the previous decade, Palestine has had the third-fastest rising population (+2.9 percent per year) in the Middle East and North African (MENA) region. Palestine has the lowest GDP yet the fastest growing economy. Future investments in energy efficiency initiatives for the industrial and commercial (I&C) sectors should benefit from the fast-growing economy. Palestine is the MENA country with the highest primary energy intensity [35] (This is defined as the ratio between total energy consumption and GDP). It is a measure of the total amount of energy required to generate a unit of GDP [35]. This suggests a relatively low energy usage and, as a result, a potential challenge in lowering consumption through energy efficiency measures in the residential sector [35]. This is especially true in Gaza, where repressed demand hits an all-time high [35]. However, Palestinian households should have the opportunity for development. Electricity accounts for the lion's share of the Palestinian energy mix, accounting for 34%. Furthermore, 60 percent of consumption is accounted for by the household sector. This demonstrates that focusing energy efficiency measures on the residential sector should have a significant influence on ultimate consumption [35].

Palestine has the largest utilization of solar water heaters in the MENA region. A solar water heater system is installed on the roof of 56 percent of homes. However, one-third of these systems are malfunctioning. Furthermore, distribution losses (both technical and non-technical) are quite substantial (20–30 percent). For the country, a large decrease in these losses would be critical. In Palestine, the cost of power is extremely expensive since 87% of its electricity is imported from other countries [1], based on the Electricity Company retail tariff. As a result, electricity accounts for the greatest percentage of Palestinian household expenditures (9%) among MENA countries. Any energy efficiency measure that reduces usage should have a quick payback period. However, in order to choose the

most appropriate activities, one must first determine what the future consumption will be between 2020 and 2030, as well as, if feasible, by using electricity [35]. In Palestine, there are limited studies addressing the issue of energy efficiency and energy retrofitting in residential buildings [36]. This study will contribute to bridge the knowledge gap and energy sustainability for this important sector. For the selected buildings, three levels of retrofitting programs were implemented. As a result, the effects of each level may be investigated separately. The money saved at each level could be utilized to lower the cost of adopting the measures at the following level. The levels are ordered by cost, feasibility, and importance with the first level being the least costly and the third level being the most costly.

### *1.2. Residential Buildings in Palestine*

Within a broad strategic context, building energy efficiency might be one of the most important opportunities for Palestine to attain energy independence. In reality, the deployment of energy efficiency measures reduces building energy demand, resulting in a reduction in energy-providing demands [37].

The Energy in Buildings and Communities Program (IEA-EBC) was created by the International Energy Agency (IEA) to produce high-quality scientific papers to help decision-makers in boosting building energy efficiency [38]. According to the IEA Annex 53 research, climate, building envelope, building systems, operations and maintenance, occupant behavior, and indoor ambient conditions all influence energy use in buildings [39].

To reduce interior environment difficulties induced by climate change, it is critical to accurately predict building performance energy and consumption. When performing energy simulations, a socio-technical approach should be used [40].

To aid Palestine's transition to more self-sufficient and sustainable energy technology, present energy use must first be assessed and improved [41]. Because many buildings may last for over a century, making them more energy efficient is essential for reducing carbon emissions and achieving a long-term energy plan. Building retrofitting in Palestine can help to alleviate the problem of energy poverty caused by a lack of natural resources and reliance on imported energy. Existing building energy retrofits can be a significant step toward energy sustainability. In Palestine, the majorities of existing residential buildings are not thermally insulated and are therefore deemed inefficient. Furthermore, research, analyses, and assessments of the potential savings from implementing viable energy retrofitting methods are lacking.

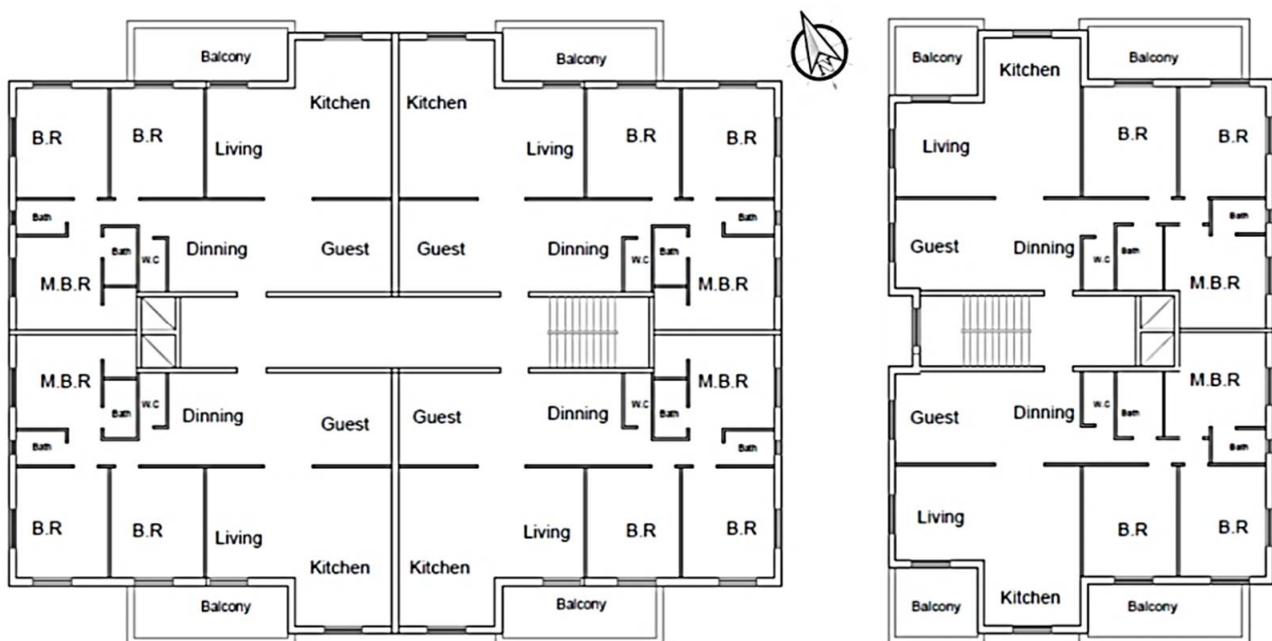
## **2. Materials and Methods**

Most energy consumptions in a typical household have been identified as domestic hot water, lighting household, heating, and cooling [42]. Those energy consumption uses were targeted in energy reduction for the proposed retrofitting plan. The Palestinian Central Bureau of Statistics has conducted a survey on energy usage in buildings [42]. The energy used for heating is a heater (electricity 39.4%, gas 25.4% or kerosene 1.2%) for 64.3% of the households, firewood of 10.7% of the households, and 2.0% have central heating. Besides the use of solar energy for water heating, which has technical losses and malfunctioning, the main energy use for domestic water heating is electricity (59.5% of households, and LPG 27.8% of households, and firewood 8.6% of households). In 2015, the average home power usage in Palestine for households who utilized electricity was 306 kWh [34]. In 2030, this value is predicted to rise to 545 kWh [35]. In 2015, the average household use of gasoline in Palestine was 95 L for families who used gasoline. In 2015, the average home usage of LPG in Palestine for gas-using families was 22 kg. In 2015, the average household consumption of kerosene in Palestine for kerosene-using families was 21 L.

Based on the above surveys for energy consumption in typical households, a retrofitting plan has been established to reduce energy consumption and contribute to the future energy sustainability for the residential building sector. The retrofit plan targets the highest energy consumers in residential buildings (heating, cooling, lighting, and domestic hot

water heating) to achieve significant benefits from the reduction plan. The retrofit plan was applied to the typical base case (BC) residential models that represent the residential building sector in terms of building size and types, building occupancy, building materials, and construction systems, and building energy use. The retrofit plan also includes different levels according to the cost, feasibility, applicability, and types of intervention. The following changes and additions have been applied to the Base Case building at the first level (L-1) of the retrofit plan includes some low-cost measures like decreasing heating set point temperature; increasing cooling set point temperature (Electronic thermostats), and other measures considered basic or important in order to move to next level like reduce infiltration. The second level (L-2) of the intervention plan includes medium-cost measures, where the following changes have been applied in addition to the L-1 measures: adding thermal insulation for external walls and roof, changing glazing, changing electric lighting, adding window shading and enhancing natural ventilation in the summer. The third level (L-3) of the intervention plan includes high-cost measures, where the following changes have been applied in addition to the L-1 and L-2 measures: best practice heating and cooling system, using mixed-mode ventilation, extra insulation for windows and installing or renovating solar water heating systems.

To assess the potential energy saving from the retrofit plan, two residential building types were selected as representative residential buildings. The selected buildings are apartment buildings which represent the most used residential building types in the Palestinian cities. The first building type is a five-story apartment; with 4 apartments on each floor, and the second building is a five-story apartment, with 2 apartments on each floor as seen in Figure 1.



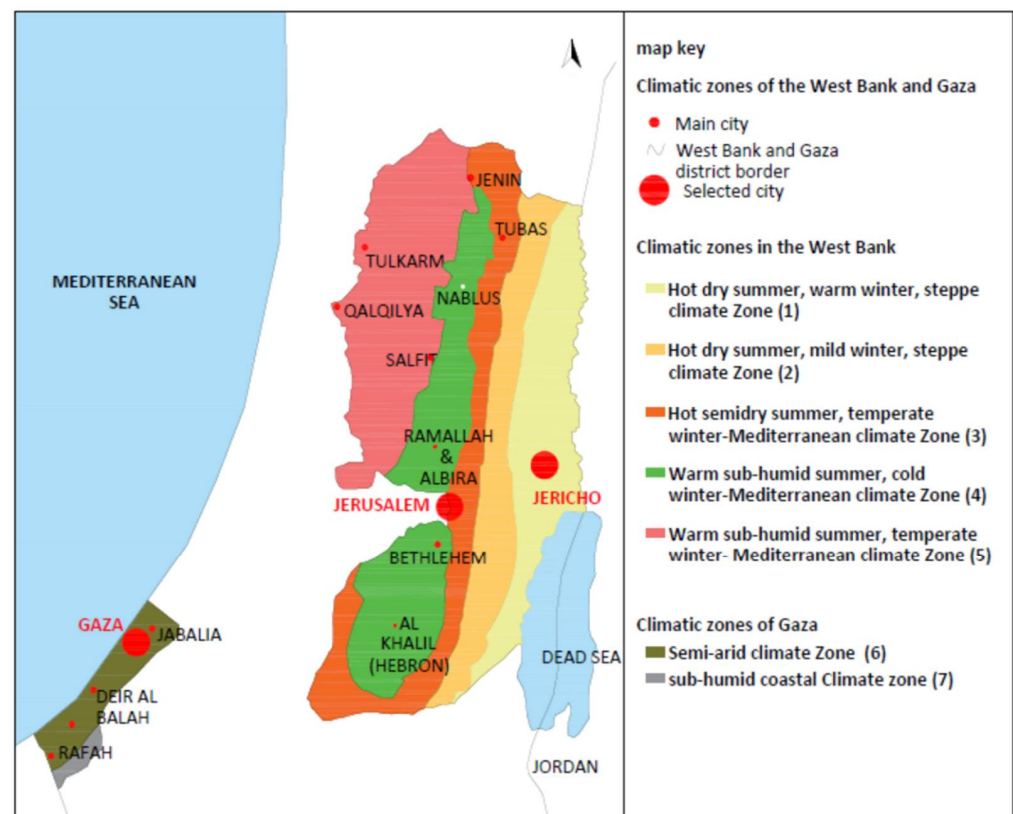
**Figure 1.** The representative building selected for the application of the retrofitting plan, on the left the building with four apartments at each floor, and, on the right, the building with two apartments on each floor.

Design builder, a computer thermal and energy simulation tool, was used to assess the effects of applying the retrofit plan on the building energy use reduction. To compare the results with a baseline building, a base case model was created to reflect the existing building energy use, occupancy, and building envelope physical properties. The energy use, occupancy, and building materials' physical properties are based on surveys and onsite conditions.

The base case building is based on existing building envelope construction materials, where external walls are composed of four layers: local stone, concrete, hollow concrete block, and plaster with a total overall heat transfer coefficient (U value) of  $2.3 \text{ W/m}^2\text{K}$ , the roof is a concrete slab with a total overall heat transfer coefficient (U value)  $2.5 \text{ W/m}^2\text{K}$ , and the windows are single 6 mm glazing with a total overall heat transfer coefficient (U value) of  $5.1 \text{ W/m}^2\text{K}$  and not shaded. The building is not well sealed with an infiltration rate of 0.8 ach. The building is using standard fluorescent lighting. The water heating systems are using natural gas and electricity. Although most residential buildings have solar water heating systems, it is either an old system or needs maintenance, so its efficiency is very low. Set point temperatures for heating and cooling were  $20 \text{ }^\circ\text{C}$  and  $23 \text{ }^\circ\text{C}$ , respectively. Occupancy for a residential building schedule was based on ASHRAE standards for five persons per household, which is the average size for families in Palestine. The natural ventilation was on in summertime with a ventilation rate of 1 ach. The load from interior equipment was considered based on the simulation tool standards values. The energy consumption from heating, cooling, lighting, and domestic hot water was calculated for the base case buildings.

The first level of the retrofit plan included modification to the base case building by reducing the infiltration to 0.25 air changes per hour (ach) (according to international green construction code), and the set point temperatures for heating and cooling were changed to  $18 \text{ }^\circ\text{C}$  and  $25 \text{ }^\circ\text{C}$ , respectively. The energy consumption from heating, cooling, lighting, and domestic hot water was calculated for the base case buildings with these modifications. The second level of the retrofit plan included further modifications to the base case building by adding thermal insulation for external walls and roof (6 cm extruded polystyrene from inside) U value  $0.5 \text{ W/m}^2\text{K}$  and changing the glazing to double low E, 3 mm, 13 mm air gap, with a total U value of  $1.53 \text{ W/m}^2\text{K}$ . Replacing standard fluorescent with CFL and LED lights, blinds from inside, and external 50 cm overhang shading were also added to the windows, and natural ventilation was enhanced from 1 to 5 ach. The energy consumption from heating, cooling, lighting, and domestic hot water was calculated for the base case buildings with these modifications. The third level of the retrofit plan included further modifications to the building by adding best practice for heating and cooling systems using mixed-mode ventilation by enhancing natural ventilation to 5 ach for summer and mechanical ventilation for winter, extra insulation for windows using triple glazing, 3 mm, 13 air with a total U value of  $0.77 \text{ W/m}^2\text{K}$  and 0.5 m overhang and internal blinds; and using new or renovated solar water heating systems. The energy consumption from heating, cooling, lighting, and domestic hot water was calculated for the base case buildings and then calculated for these modifications at each level of the retrofitting plan. At level three of the retrofit plan, the energy for mechanical ventilation is considered under the required energy for heating.

To evaluate the retrofit plan in different climate contexts in Palestine, three out of seven different climatic regions were considered for the energy simulation. The selected climatic zones represent the regions with high population density and cover the main climatic conditions as seen in Figure 2. The first climatic zone (zone 1) represented by the city of Jericho, which is 3A according to ASHRAE climate zones, and a Csa (C) Temperate,(s) Dry summer, (a) Hot summer according to Koppen's climate classification. It has an elevation of 300 m below sea level and is characterized by hot and dry summers and warm winters. The second climatic zone (zone 4) represented by the city of Jerusalem, which is 3C according to ASHRAE climate zones, and a Csa according to Koppen's climate classification. It has an elevation of 750 m above sea level and is characterized by hot summers and cold winters. The third climatic zone (zone 6) is represented by the city of Gaza, which is 3A according to ASHRAE climate zones, and a Csa according to Koppen's climate classification. It has an elevation of 5 m above sea level and is characterized by hot humid summers and moderate winters.



**Figure 2.** Climatic zones in the Palestinian territories are developed by the authors based on the information provided by Applied Research Institute—Jerusalem (source: ARIJ) [43].

### 3. Results and Discussion

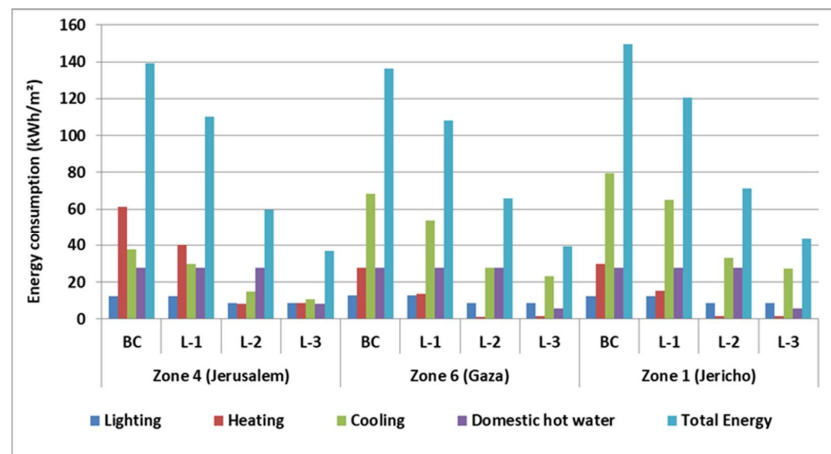
The simulation results for applying the retrofit plan on two residential building types and three climatic zones in Palestine using design-builder simulation tools show a significant reduction in energy for heating, cooling, lighting, and domestic hot water use.

For the residential buildings with two units per floor buildings, the simulation results show that applying level 1 of the retrofit plan can reduce the annual total energy by 21% compared with the base case building for climatic zones 4 and 6 (from 139 kWh/m<sup>2</sup> to 110 kWh/m<sup>2</sup> and from 136 kWh/m<sup>2</sup> to 108 kWh/m<sup>2</sup>, respectively), and by 19% for climatic zone 1 (from 150 kWh/m<sup>2</sup> to 121 kWh/m<sup>2</sup>). These reductions show the importance of reducing the infiltration and set point temperatures. By applying the combination of level 1 and level 2 of the retrofitting plan, the reduction in total energy compared to the base case was 57%, 51%, and 53% for Zones 4, 6, and 1, respectively. Adding level two measures such as thermal insulation, shading, lighting and natural ventilation led to a further reduction compared to level one of 32% to 36% of the energy for heating, lighting, and cooling. Finally, applying the three levels of the retrofitting plan can result in a total reduction in total energy compared with the base case by 73% for zone 4 and 71% for zones 6 and zone 1 as can be seen in Table 1. In this case, the level three measures such as efficient HVAC and solar water heating led to a further reduction compared to the last two levels by 16% to 20% depending on the climate zone.

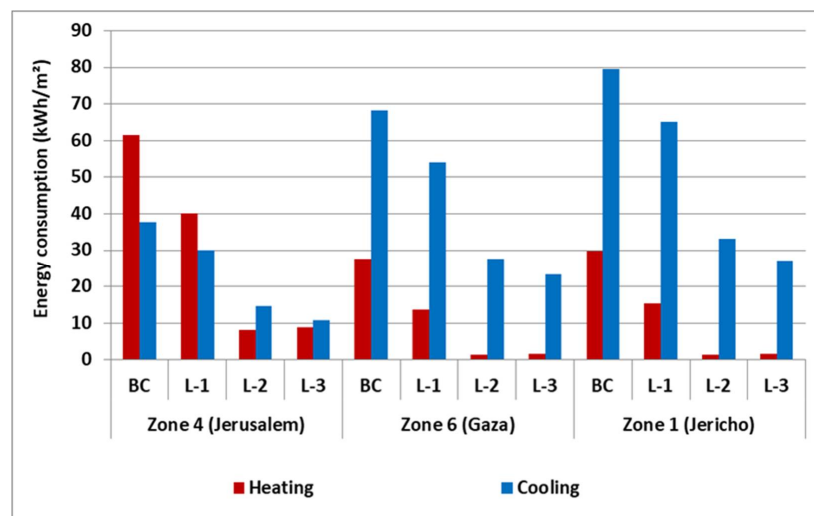
When applying the first level of the retrofitting plan, the significant reduction was for energy for heating (from 61 kWh/m<sup>2</sup> to 40 kWh/m<sup>2</sup>) followed by the energy for cooling (from 38 kWh/m<sup>2</sup> to 30 kWh/m<sup>2</sup>) in zone 4 because of the climatic characteristics of heating dominance. For zones 6 and 1, which are characterized by cooling dominance, the reduction for heating and cooling had a similar effect as can be seen in Figures 3 and 4.

**Table 1.** Results from the simulation for energy consumption for lighting, heating, cooling, and domestic hot water, comparing the base case scenario with the three-level retrofit plans for buildings with two units per floor area.

Climate Zone/City	Retrofit Plan	Lighting kWh/m <sup>2</sup>	Heating kWh/m <sup>2</sup>	Cooling kWh/m <sup>2</sup>	Domestic Hot Water kWh/m <sup>2</sup>	Total Energy kWh/m <sup>2</sup>
Zone 4 (Jerusalem)	Base Case (BC)	12	61	38	28	139
	Level 1 (L-1)	12	40	30	28	110
	Level 2 (L-2)	9	8	15	28	59
	Level 3 (L-3)	9	9	11	8	37
Zone 6 (Gaza)	Base Case (BC)	13	28	68	28	136
	Level 1 (L-1)	13	14	54	28	108
	Level 2 (L-2)	9	1	28	28	66
	Level 3 (L-3)	9	2	23	6	39
Zone 1 (Jericho)	Base Case (BC)	12	30	80	28	150
	Level 1 (L-1)	12	15	65	28	121
	Level 2 (L-2)	9	2	33	28	71
	Level 3 (L-3)	9	2	27	6	43



**Figure 3.** Total energy saving from applying the retrofitting plan for two residential units per floor area in different climate zones in Palestine.



**Figure 4.** Saving in energy for heating and cooling from applying the retrofit plan on buildings with two residential units per floor area in different climatic zones in Palestine.

Applying the first and second levels of the retrofitting plan has a further significant reduction in heating (from 40 kWh/m<sup>2</sup> to only 8 kWh/m<sup>2</sup>) followed by the effect on cooling from 30 kWh/m<sup>2</sup> to 15 kWh/m<sup>2</sup> and the lowest effect on lighting (from 12 kWh/m<sup>2</sup> to 9 kWh/m<sup>2</sup>) for climatic zone 4. For zones 6 and 1, the significant further reduction is for energy for cooling (from 54 kWh/m<sup>2</sup> to 28 kWh/m<sup>2</sup> and from 65 kWh/m<sup>2</sup> to 33 kWh/m<sup>2</sup>) followed by energy for heating (from 14 kWh/m<sup>2</sup> to 1 kWh/m<sup>2</sup> and 15 kWh/m<sup>2</sup> to 2 kWh/m<sup>2</sup>), and, finally, the lowest effect was on the energy for lighting (from 13 kWh/m<sup>2</sup> to 9 kWh/m<sup>2</sup> and 12 kWh/m<sup>2</sup> to 9 kWh/m<sup>2</sup>) as can be seen in Figures 3 and 4.

For the residential buildings with four units per floor buildings, the simulation results show that applying level 1 of the retrofit plan can reduce the annual total energy by 24% and 23% compared with the base case building for climatic zones 4 and 6 (from 127.2 kWh/m<sup>2</sup> to 96.6 kWh/m<sup>2</sup> and from 126.2 kWh/m<sup>2</sup> to 97.0 kWh/m<sup>2</sup>, respectively), and by 22% for climatic zone 1 (from 138.1 kWh/m<sup>2</sup> to 107.9 kWh/m<sup>2</sup>). This reduction was slightly higher than the reduction for two residential units per floor type. By applying the combination of level 1 and level 2 of the retrofitting plan, the reduction in total energy compared to the base case was 56%, 50%, and 51% for Zones 4, 6, and 1, respectively, which is very close to two residential units per floor type. Finally, applying the three levels of the retrofitting plan can result in a total reduction in total energy compared with the base case by 80% for zone 4 and 73% for zones 6 and zone 1 as can be seen in Table 2, which is higher than the reduction for two residential units per floor type.

**Table 2.** Results from the simulation for energy consumption for lighting, heating, cooling, and domestic hot water, comparing the base case scenario with the three-level retrofit plans for buildings with four units per floor area.

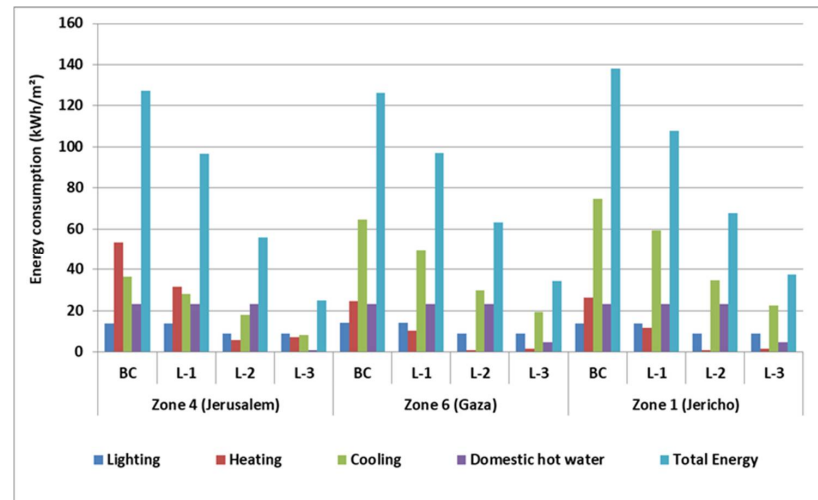
Climate Zone/City	Retrofit Plan	Lighting kWh/m <sup>2</sup>	Heating kWh/m <sup>2</sup>	Cooling kWh/m <sup>2</sup>	Domestic Hot Water kWh/m <sup>2</sup>	Total Energy kWh/m <sup>2</sup>
Zone 4 (Jerusalem)	Base Case (BC)	13.9	53.6	36.5	23.1	127.2
	Level 1 (L-1)	13.9	31.5	28.0	23.1	96.6
	Level 2 (L-2)	9.0	5.7	18.0	23.2	55.9
	Level 3 (L-3)	9.0	7.0	8.2	0.7	24.9
Zone 6 (Gaza)	Base Case (BC)	14.1	24.4	64.6	23.1	126.2
	Level 1 (L-1)	14.1	10.3	49.5	23.1	97.0
	Level 2 (L-2)	9.0	1.0	30.0	23.2	63.2
	Level 3 (L-3)	9.0	1.4	19.4	4.6	34.4
Zone 1 (Jericho)	Base Case (BC)	13.9	26.2	74.7	23.1	138.1
	Level 1 (L-1)	13.9	11.6	59.2	23.1	107.9
	Level 2 (L-2)	9.0	1.1	34.7	23.2	67.9
	Level 3 (L-3)	9.0	1.5	22.6	4.6	37.6

By applying the first level of the retrofitting plan, the significant reduction was again for energy for heating (from 53.6 kWh/m<sup>2</sup> to 31.5 kWh/m<sup>2</sup>), followed by the energy for cooling (from 36.5 kWh/m<sup>2</sup> to 28 kWh/m<sup>2</sup>) in zone 4; this is because of the climatic characteristics of heating dominance. For zones 6 and 1, which are characterized by cooling dominance, the reduction for heating and cooling had a similar effect as can be seen in Figures 5 and 6.

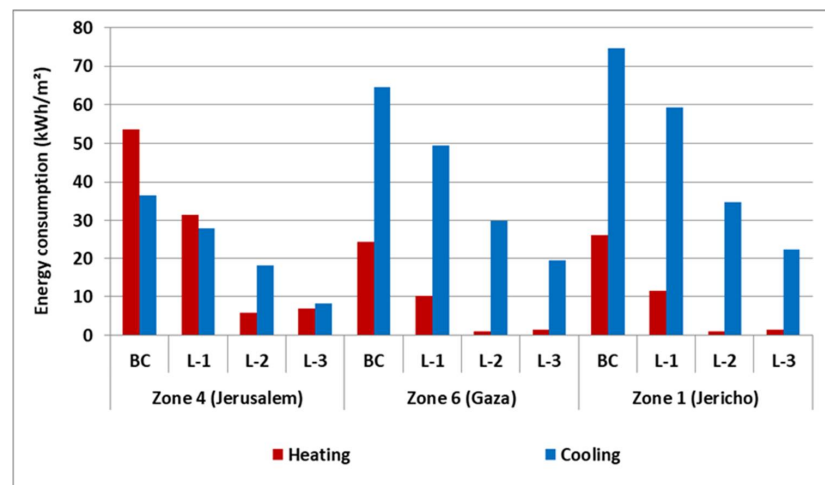
Applying the first and second levels of the retrofitting plan has a further significant reduction in heating (from 31.5 kWh/m<sup>2</sup> to only 5.7 kWh/m<sup>2</sup>) followed by the effect on cooling from 28 kWh/m<sup>2</sup> to 18 kWh/m<sup>2</sup> and the lowest effect on lighting (from 13.9 kWh/m<sup>2</sup> to 9 kWh/m<sup>2</sup>) for climatic zone 4. For zones 6 and 1, the significant further reduction is for energy for cooling (from 49.5 kWh/m<sup>2</sup> to 30 kWh/m<sup>2</sup> and from 59.2 kWh/m<sup>2</sup> to 34.7 kWh/m<sup>2</sup>) followed by energy for heating (from 10.3 kWh/m<sup>2</sup> to 1 kWh/m<sup>2</sup> and



11.6 kWh/m<sup>2</sup> to 1.1 kWh/m<sup>2</sup>) and, finally, the lowest effect was on the energy for lighting (from 14.1 kWh/m<sup>2</sup> to 9 kWh/m<sup>2</sup> and 13.9 kWh/m<sup>2</sup> to 9 kWh/m<sup>2</sup>) as can be seen in Figures 5 and 6.



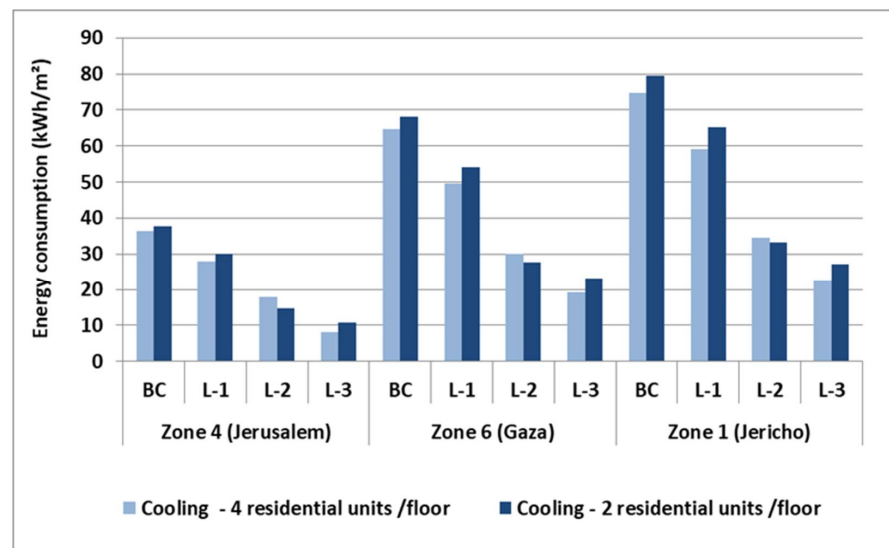
**Figure 5.** Total energy saving from applying the retrofitting plan for four residential units per floor area in different climate zones in Palestine.



**Figure 6.** Saving in energy for heating and cooling from applying the retrofit plan on buildings with four residential units per floor area in different climatic zones in Palestine.

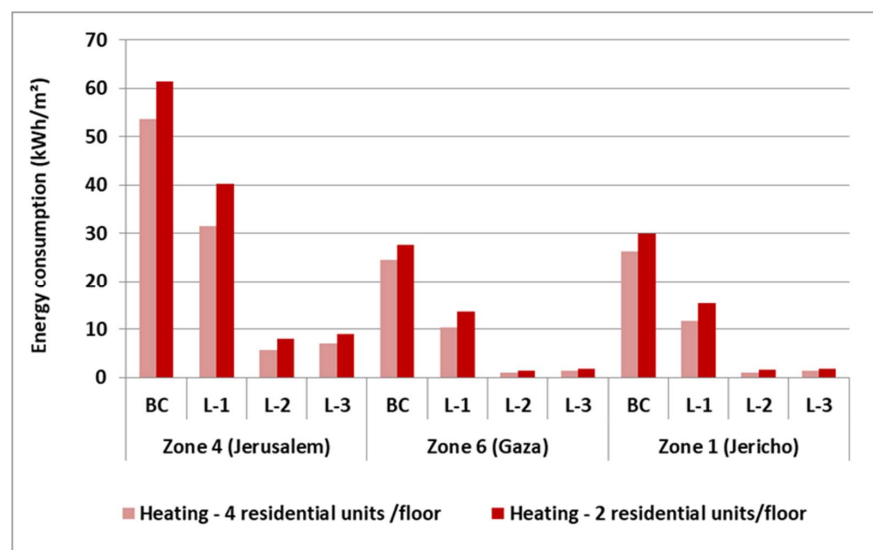
When comparing the effect of the retrofitting plan for the two building types in three different climatic zones, the energy for cooling was slightly higher in the building with two units than in buildings with four units in the base case scenario for all climatic zones. This can be justified by the creator's exposure to the sun in the two residential units, as can be seen in Figure 7. When applying level one of the retrofitting plans, the cooling load has a higher reduction in zones 6 and 1 than for zone 4; however, the cooling load for the two residential buildings units has higher energy consumption for cooling compared to the four residential units building. By applying the combination of levels 1 and 2 of the retrofitting plan, there was a further reduction in energy for cooling; however, the cooling load for the building with two units has higher reduction than the cooling load for the four unit's buildings; this can be justified by avoiding the effect of the direct sun through shading and the effectiveness of natural ventilation. When applying the three levels of the retrofitting plan, the cooling load for two units building is again higher than the four

unit's buildings; this can be justified by the effect of the optimized HVAC system and level 1 effects combined higher than the effect of level 2 on the two types of buildings.



**Figure 7.** Comparing the saving in energy for cooling from applying the retrofit plans on buildings with two residential units per floor area versus four residential units per floor area in different climatic conditions in Palestine.

When comparing the effect of the retrofitting plan for the two building types in three different climatic zones, the energy for heating was significantly higher in the building with two residential units per floor than in buildings with four units in the base case scenario for all climatic zones. This can be justified by the greater exposure to the outdoor environment for the two residential units. When applying the three levels of the retrofitting plan, the heating load has a higher reduction in zone 4, which is a winter heating dominant climate compared to zones 6 and 1, which are summer cooling dominant climates. Again, the heating load for the two residential buildings units still has higher energy consumption compared to the four residential units building; however, the difference is less than that of the base case building as can be seen in Figure 8.



**Figure 8.** Comparing the saving in energy for heating from applying the retrofit plans on buildings with two residential units per floor area versus four residential units per floor area in different climatic conditions in Palestine.

#### 4. Conclusions

The high energy prices, dependency on imported energy, the energy inefficient construction systems, and the large share of energy consumed in residential buildings have led to the importance of considering the energy retrofitting in the residential sector in Palestine, especially for existing buildings. This paper has established a three-phase retrofit plan that includes different levels of actions to improve energy use for heating, cooling, lighting, and domestic water heating, as they are the major energy consumers in residential buildings. The purpose of categorizing energy efficiency measures into levels is to investigate the effects of each level separately. Each level's savings will cover a reasonable amount of the cost of the following level's measures. The cost of each level is separated into three categories; the higher the level, the more expensive it is. In fact, level one will have a very low cost compared with the cost for level two; however, level two is important to have overall significant reduction. Level three can represent a huge investment and can be delivered at a later stage. The cost analysis was not addressed in this article as it is focusing on potential energy saving simulation. The cost saving in energy consumption at each level from applying the selected measures, and the cost of the retrofitting actions needs further analysis in future studies.

The computer energy performance simulation tool was used to evaluate the effects on energy saving and the feasibility of applying such a retrofit plan. The results from the simulation show that the suggested retrofit plan could have significant reductions on the energy use in two different selected residential building types for three different climatic zones. The reductions depend on the retrofit level, building type, and climatic zones, where it had a range from 19 percent when one level of the retrofit plan was used to up to 80 percent when the three levels of the retrofit plan were applied. Building types and climatic zones should be taken into consideration in the establishment and the application of retrofitting.

By combining level 1 and level 2 of the retrofitting plan, overall energy consumption was reduced by 51 to 57 percent and 53 percent, respectively. Adding level two measures resulted in a reduction of 32 percent to 36 percent as compared to level one. Finally, using the three levels of the retrofitting plan can result in a total energy savings of 71 percent to 73 percent when compared to the basic case. In this case, the level three measures resulted in a decrease of 16 to 20% in comparison to the previous two levels, depending on the climatic zone.

Although the retrofit plan was applied to existing residential buildings, new construction can implement some actions on the retrofit plan during the design and construction of new buildings. Moreover, the energy production from PV installation, as suggested in other studies [32], can provide the energy needed after applying the retrofit plan; this way, residential buildings could be near zero or even energy positive buildings.

Finally, the limitations for this research could be that the study used a typical building outline for only two of the most used building types. In addition, the research was applied to only three climatic zones that represent the highest population density in Palestine. Other building types and other climatic zones need further analysis.

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