Scientific Research Publishing

Open Journal of Energy Efficiency, 2025, 14(1), 1-20
https://www.scirp.org/journal/ojee
ISSN Online: 2169-2645
ISSN Print: 2169-2637

Net Zero Energy Building: A Case Study Using ECOTECT Software under Beirut Weather Conditions

Fadl Bdeir[1]*, Chadi Nasrallah[2]

[1]Industrial Engineering Department, Maroun Semaan Faculty of Engineering and Architecture, American University of Beirut, Beirut, Lebanon
[2]Civil Engineering Department, Order of Engineers, Beirut, Lebanon
Email: *fbdeir@gmail.com

How to cite this paper: Bdeir, F. and Nasrallah, C. (2025) Net Zero Energy Building: A Case Study Using ECOTECT Software under Beirut Weather Conditions. *Open Journal of Energy Efficiency*, **14**, 1-20.
https://doi.org/10.4236/ojee.2025.141001

Received: January 22, 2025
Accepted: March 17, 2025
Published: March 20, 2025

Abstract

We investigated the concept of NZEB and applied it to a case study of a 100 m^2 home in Beirut weather using Ecotect software. A number of passive design strategies, including building envelope, orientation, glazing, and shading, will be studied in the first segment to optimize the building's energy efficiency. In the second segment, a renewable energy source will be used to cover the remaining load necessary to meet the NZEB criteria. Our research indicates that 192.5° is the optimal facade orientation to minimize solar gains throughout the summer. Double walls measuring 10 cm with a 4 cm air gap make up the perfect wall envelopes. The results of the glazing and shading study showed that windows with a timber frame, a low E coat, and an overhanging west façade with a 6 mm air gap would all help to lower the energy needed. 46% of the savings were realized.

Keywords

Green Buildings, Net Zero Energy Building, Passive Design, Energy Efficiency, Envelope

1. Introduction

There is rising concern about climate change and the increase in global average temperature which are attributed to greenhouse emissions. These emissions are the result of human activity like the use of fossil fuels such as petroleum, natural gas, and coal [1]. The built environment is responsible for about 42% of annual global CO$_2$ emissions. Of those total emissions, buildings operations are responsible for 27% while the embodied carbon of just four building and infrastructure materials namely cement, iron, steel, and aluminum are responsible for an additional 15% annually [2].

Lebanon, a small country on the eastern side of the Mediterranean, is heavily reliant on fossil fuels as a UNDP recent report shows that Lebanon's greenhouse gas (GHG) emissions are increasing at an average rate of 3.4% every year, which leads to a doubling of emissions since 1994. These emissions are mainly from the energy sector which alone constituted 53% to 59% of the total emissions during this period [3].

In response to the GHG emissions, sustainable approaches are becoming a priority. One of these approaches is the net zero energy building NZEB which means conceptually that the total energy used by the building on an annual basis is equal to the energy produced on-site.

Since ancient times, man has found ways of using and converting natural resources to improve living conditions and among these are houses and their construction techniques. Even if "energy efficiency" was not as common a term as it is nowadays, before the 20th century, people have created and transferred from one generation to another the good practice codes of efficient energy practices [4].

It is hard to locate a building that can be considered the first NZEB. However, few publications appeared in the late 70s and early 80s, in which phrases "A zero energy home or an autonomous energy house" or an "energy-independent house" were used [5].

"House of tomorrow" by George F. Keckand "MIT Solar House1" of Hoyt C. Hottelbuiltin 1930s demonstrated the important heat gains from the Sun [6]. The two buildings started the stream concept of energy efficiency in buildings based on scientific methodologies of calculation, strategies of design and construction.

The oil crisis in 1973 amplified the interest in the energy efficiency of buildings. The concepts of building tightness, super insulation, heat recovery from ventilation systems, and passive technologies became widely known. Brenda and Robert Vale coined the terms self-sufficient houses, autonomous houses and greenhouse [7].

In the late 80s, inspired by the energy-efficient houses of the 1970s, Wolf gang Feistin collaborated with Bo Adam son to sketch the concept of "Passive House". The Passive House concept outlined at the beginning of the 90s integrated all the valuable theories and algorithms of design [8].

The first energy-autonomous house designed and built by Fraunhofer Institute for Solar Energy from Freiburg; Germany was in 1992. Due to well-designed insulation and solar energy technologies, the house was able to cover its own needs without the help of external energy sources [9].

Research and studies have continued on sustainability and passive building strategies. Iqbal defined NZEB as the term used for a building that incorporates available renewable energy technologies commercially with energy efficiency construction methods where no fossil fuels are consumed [10]. Kilkis defined NZEB as a building, which has a total annual amount of zero energy transfer through the building during all-electric and other transfers that occur during a particular time span [11]. Laustsen gave the general definition for ZEB: zero-energy buildings do not use fossil fuels and rely entirely on solar and other renewable energy sources to meet their energy needs [12]. Noguchi defined NZEB as a house that consumes as much energy as it produces over a certain period of time [13]. Similarly, Berardi discussed their methodologies for the design and evaluation of ZEB and NZEB [14].

Furthermore, Ghaith Tibi, Nesreen Ghaddar and Kamel Ghali (2013) performed a case study using Ecotect software for a detached residence located in Lebanon inland region, where they applied passive design strategies that could save up to 78% of the annual heating and cooling electric energy consumption, taking into consideration geometry, envelop, orientation, natural ventilation with other factors [15]. Shading devices were not taken into consideration.

Between 2014 and 2035, the global market for goods and services related to NZEB construction and renovation is expected to rise at a compound annual growth rate of 44.5%, surpassing $1.4 trillion last year. This is an indication that the concept of NZEB is getting popular. Caulfield discussed the exponential popularity growth of the NZEB for the next two decades [16].

The concept of zero-energy buildings has enjoyed many definitions stemming from the above-described evolution and development. Some of these definitions might differ from each other, yet the main concept is that a net zero energy building is characterized by a significant reduction in its energy demands achieved through efficiency measures. This enables the residual energy needs to be met through the use of renewable technologies.

The development of net-zero-energy buildings (NZEBs) is based on four concepts. Based on the typology of the building and the climatic context, design teams must apply these four principles to find the most suitable measures that follow these steps or principles [17]. First: Reducing the energy demand for all newly constructed buildings. About 40% of all energy consumed by buildings is used for space heating and cooling. This reduction can be applied by adopting passive design strategies. Second: Improving indoor environmental quality (IEQ). Third: Applying a percentage of renewable energy demands to be covered by a renewable energy annual balance. Fourth: Reducing the overarching value for primary energy consumption and carbon emissions per year.

The basic concept behind the NZEB standard exacerbates the risk of overheating in homes under hotter weather conditions. Despite this, there is very little research and investigation regarding the issue and the potential of the widespread implementation of NZEB standards across Europe to compound the risk of overheating in buildings [17].

Fundamental to the energy efficiency of these buildings, the following five principles are central to Passive House design and construction: 1) super-insulated envelopes, 2) airtight construction, 3) high-performance glazing, 4) thermal-bridge-free detailing, and 5) heat recovery ventilation.

All these key principles are linked to an impact each other in the design. To effectively create a Passive House building, the design should be looked at holistically to incorporate all five design principles. Passive design strategies are decided based on the climate of the region, mainly temperature and humidity. There are many passive design strategies, from passive heating to passive cooling and passive ventilation.

2. Research Methodology

The research will discuss passive strategies such as passive heating design to achieve NZEB, and then will apply the NZEB concept on a 100 m^2 square house under Beirut weather conditions by using Ecotect software to study the effects of different variables such as orientation, building envelope, glazing and shading, and then propose the optimal conditions for NZEB under Beirut weather conditions. After studying different alternatives and selecting the one that optimizes the energy needed, we will proceed with renewable energy system calculation to cover the remaining needed load.

2.1. Passive Heating Design

In Passive solar heating, the building envelope composed of walls, floor, roof and windows is designed to collect, store, reflect and distribute solar energy in form of heat in the winter and reject heat in summer. Energy from sun is being used, or controlled, through the physical makeup of the spaces.

Passive solar design depends on the location of the building, orientation, geometry, envelope and other factors to achieve the target.

2.1.1. Orientation of the Building

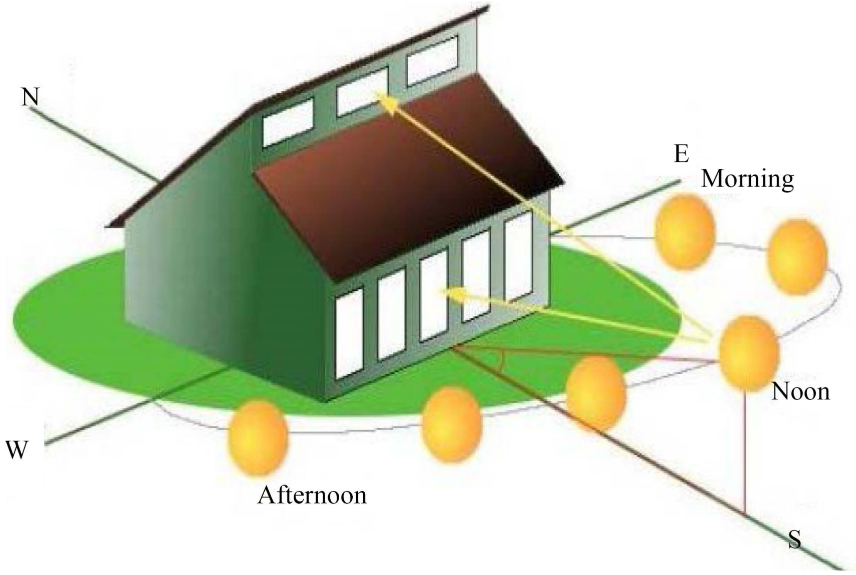


Figure 1. Example of passive house orientation.

Solar passive design technique puts forth light upon the orientation of the building as it affects the solar radiation, daylight, and wind. In a hot and humid climate, the orientation of the buildings should be along the long axes in the east-west direction. This will eventually place the longest façade in north and south direction along with a short wall facing the east and west direction (**Figure 1**).

2.1.2. Building Geometry

The form of the building can affect solar access, wind exposure, rate of heat loss or heat gain through the external envelope of the structure as well as airflow pattern around the structure, which will also affect the ventilation. The compactness of the structure can be measured with the help of the ratio of surface area to the volume (S/V). The lowest S/V ratio is believed to be of circular geometry. Thus, the circular form of the building becomes the most energy-efficient in a hot and humid climate.

2.1.3. Envelope

The building envelope is what separates the interior of the building from the exterior; it consists of windows, outside walls, roofs, and floors.

Windows: to balance the amount of light admitted into the structure with the control of solar heat gain and conduction of energy. Up to 40% of a home's heating energy can be lost and up to 87% gained through glazing. Window performance is a combination of several factors.

Thermal transmittance of the walls is the heat flow rate in a steady state divided by area and the temperature difference between the surroundings on each side of a system. Solar heat gain coefficient (SHGC), represents the fraction of solar heat that enters the window and becomes heat; it includes both directly transmitted and absorbed solar radiation. The lower the SHGC, the less solar heat the window transmits through the glazing from the exterior to the interior and the greater shading capability. Visible transmittance (VT) of the glass VT (0 to 1): percentage of visible spectrum that is transmitted through the glazing. LSG: The ratio SHGC/VT: Light-to-solar-gain (LSG) ratio is a gauge of the relative efficiency of different glass types in transmitting daylight while blocking heat gains.

It is important not only to make sure to specify high-performance windows but also to carefully consider how they are incorporated into the building design. Solar heat gain through appropriately placed windows can help offset the amount of heat a building needs during colder months. During the summer months, this needs to be counteracted with shading to prevent too much heat from the sun from getting into the building, causing overheating.

Walls: walls consist a major element in a building envelope. One of the characteristics is the thermal transmittance, which represents the heat flow rate in the steady state divided by area and the temperature difference between the surroundings on each side of a system. Thermal mass of the exterior surface that receives direct sunlight during the day and placement of insulation with respect to the building façade.

Roof: a roof of a high-performance building is especially important because it is a major area for heat transmission due to its generally large area and exposure to the sun:

Using surfaces with high albedo (a measure of the reflectivity of solar radiation) for roofing can reduce the ambient air temperature so that the entire area is cooler, which helps reduce the thermal load on the building as well as the surrounding neighborhood.

The Solar Reflectance Index (SRI): measures how hot materials are in the sun–used to easily describe the amount of solar energy reflected by roofing materials. A building with light-colored shingles and an SRI of 54 would reflect 54% of incident solar energy, & would be very cool relative to a building with conventional dark shingles.

Insulation and thermal bridges: Insulation is a critical element of the building envelope.

Insulation acts as a barrier to heat flow and is essential for keeping the home warm in winter and cool in summer. Some types of insulation can also help with weatherproofing and soundproofing. Passive House makes the most of the envelope by super-insulating the building in order to minimize heat loss. The result is a significant increase in the thermal performance expected from the building envelope. When a material bypasses the insulation, it is known as a thermal bridge and can significantly reduce the effectiveness of insulation, especially if that material is very conductive, like metal. Minimizing repeating thermal bridges and aiming for continuous insulation where possible, helps make the most of the insulation within the building envelope.

2.2. Software Used

ECOTECT software is an environmental analysis tool that allows architects and designers to simulate building performance right in conceptual phase [18]. It allows to calculate building's energy consumption by simulating its context within the environment, especially on dealing with solar heat, its nature for day-lighting, natural airflow for ventilation, and its energy consumption for man-made systems such as Air Conditioning and Lighting.

2.3. Base Case Model Description, Parameters and Performance

2.3.1. Beirut Weather Conditions

Lebanon, with a total area of 10.452 km^2, is located in the East Mediterranean and extends over some 210 km along the coast and 50 km inland. The climate in Lebanon is characterized in general by the existence of a cold winter season, a hot summer season and two mild mid-seasons: the summer season extends from July till September with August being the hottest month.

Lebanon is divided into four regions based on temperature, relative humidity and solar radiation as per **Table 1**. These climatic parameters affect the heating and cooling requirements in buildings. Beirut, which is our case study, fall under

Zone 1: Coastal, characterized by a warm and short winter, and a hot and humid summer.

Table 1. General characteristics of climate zones and sub-zones [19].

Climatic Zone	Climatic Sub-Zone	Winter	Summer	Dally Gap
1 Coastal	1A Altitude < 400 m	Warm and short	Hot and humid	Small all year
	1B Altitude > 400 m	Cold and long increasing with altitude	Hot and humid with maximum daily temperatures differing slightly from 1A	
2 Western Mid Mountain	No Sub-zone	Cold and long increasing with altitude	Cool and Moderate summer	More pronounced than the daily gap of zone 1
3 Inland Plateau	No Sub-zone	Colder and longer than the winter at same altitudes in zones 1 & 2 (min temperatures lower than zones 1 & 2)	Hot and dry summer, but cool at night. The min temperatures are lower than zones 1 & 2 and the max temperatures are higher. Very low humidity.	In summer the daily gap is high and varies according to the year.
4 High Mountain	No Sub-zone	Long and rigorous	Cool	Moderate to high in Eastern Mountain

2.3.2. Base Case Model Parameters

The house is a single floor one, with a rectangular shape of 12.5 m x 8 m, and a height of 3 m, the long façades face the east and west. The envelope has an infiltration rate of 0.5 air change per hour (ACH) with a U-value of 4.021 w/m^2. C. The external walls are composed of 1.5 cm plaster, 15 cm hollow block, and 1.5 cm plaster. Slabs are made from reinforced concrete without insulation, same for the roof. Windows are made from 6mm single glass panes.

Table 2 summarizes the U values of the base case model, while Figure 2 shows the building floor plan.

To note that the envelope thermal transmittance (U) is higher than the maximum value set by the local building code for the same region of 2.5 W/(m^2 K) [19].

The house is divided into two zones. The first one is composed of bedrooms, and it is assumed that is occupied only at night during sleeping hours, while the second one is the kitchen with salon and living room, and it is assumed to be occupied during the day and in the evening. The zoning is used to design the operation such as number of people which is equal to 3, the type of active system which is mixed that is used to provide for both heating and cooling for the house, and operating hours depending on each zone schedule.

Table 2. Thermal characteristics of the building's envelope.

Component	Description	U Value (W/m^2.K)
Roof	plaster-Reinforced concrete-sand-mortar-tiles	2.64
Walls	Plaster-Hollow block-plaster	4.95
Windows	Aluminum frame single pan	5.41
Slabs	Reinforced concrete-sand mortar-tiles	4.06

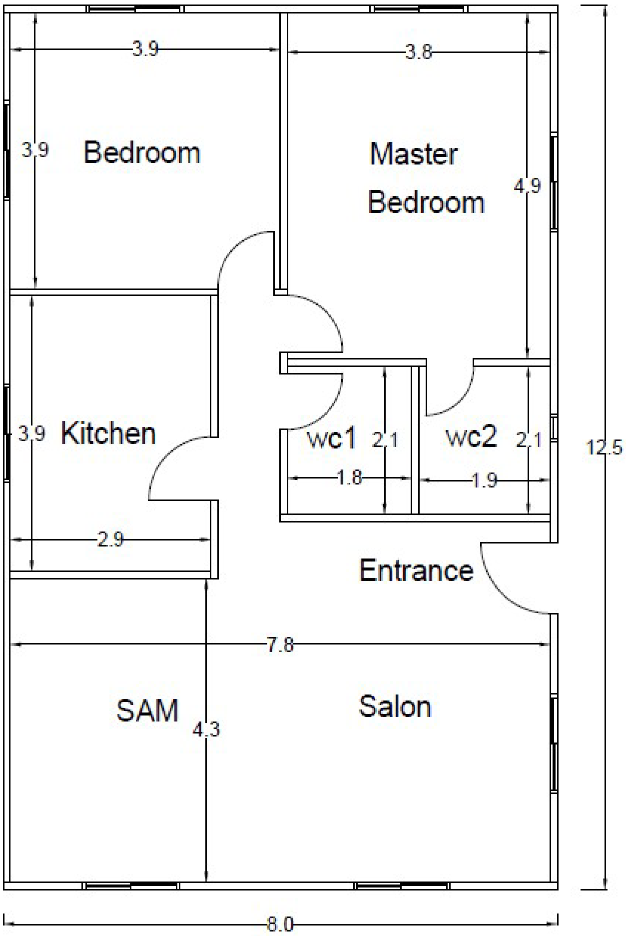


Figure 2. Building floor plan.

The weather file used to simulate Lebanon weather data for Beirut area is the one of Rafiq Hariri International Airport [20]. For this case study, we will adopt the following parameters: internal loads, including occupants, lighting, and appliances, are approximated to be 5 w/m^2 of sensible load, and 3 w/m^2 of latent load. The thermal comfort band is set to be between 18°C and 26°C.

2.3.3. Energy Consumption in Building Sector in Lebanon

Individual household energy consumption in Lebanon estimates vary from 0.45 to 2.2 MWh per household [21]. Although no studies were found identifying per capita residential energy consumption, several values were obtained for total per capita energy consumption varying from 2.0 to 2.6 MWh capita [22]-[24].

In 2007, final power consumption remains concentrated at 65% in the residential sector and the tertiary sector, then at 30% in the industrial sector, and finally at 5% in the other sectors (agricultural and administrative).

In Lebanon, 67% of housing consists of flats in several-floor buildings. 52% of the housing units are 4 to 5 rooms. The average housing area in Lebanon is 129.3 m^2. 21.8% of the housing units are power heated, 25% use fuel oil, 27.3% gas (LPG), 17.6% wood or coal [25] (**Figure 3**).

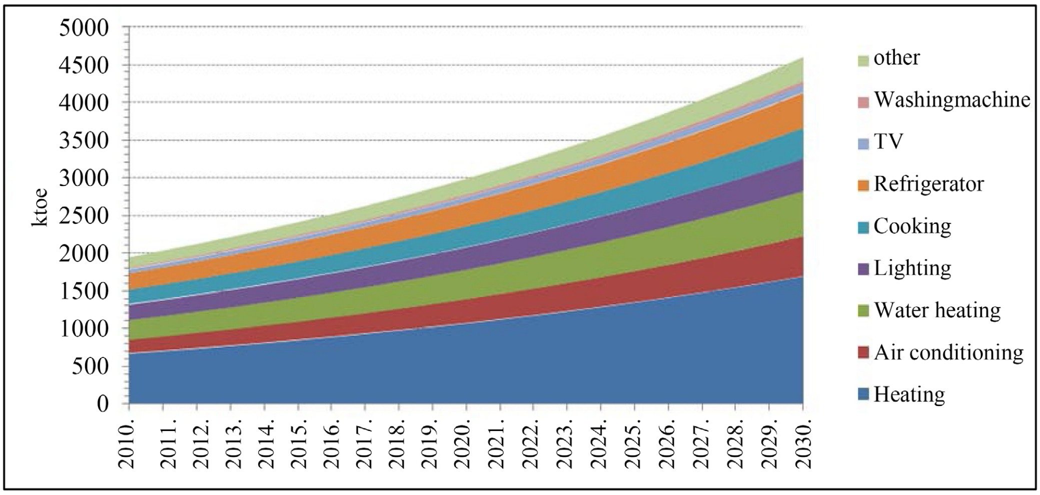


Figure 3. Energy consumption in Lebanon, by use in the residential sector [26].

3. Results

3.1. Base Case Model Results

The direct normal irradiation and the annual sun path analysis for the base case model are shown in **Figure 4** and **Figure 5** respectively.

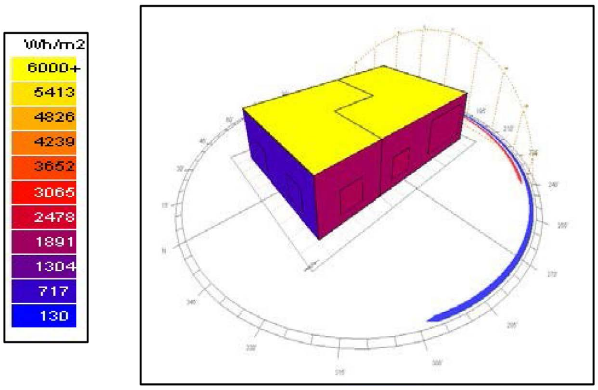


Figure 4. Direct normal irradiation for base case model.

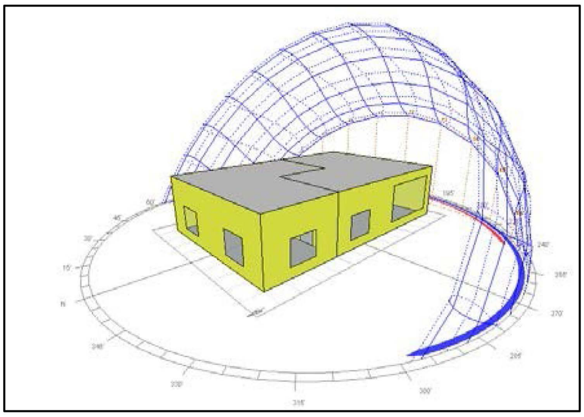


Figure 5. Annual Sun path for the base case model.

The simulation of the base case model showed that the annual cooling load is 27.25 kw/m^2 with a peak of 3.95 kw on the 9th of July, while the annual heating load is 1.68 kw/m^2 with a peak of 0.99 kw on the 6th of February.

Table 3 summarize the monthly cooling and heating loaded in wh, while **Figure 6** represent the combined heating and cooling loads during the year.

Table 3. Monthly heating and cooling loads in Wh.

	Heating	Cooling	Total
MONTH	(Wh)	(Wh)	(Wh)
Jan	84,241	-	84,241
Feb	40,856	-	40,856
Mar	16,761	-	16,761
Apr	-	-	-
May	-	21,807	21,807
Jun	-	323,900	323,900
Jul	-	701,805	701,805
Aug	-	851,132	851,132
Sep	-	623,371	623,371
Oct	-	186,048	186,048
Nov	11,326	17,559	28,884
Dec	15,614	-	15,614
TOTAL	168,797	2,725,622	2,894,420

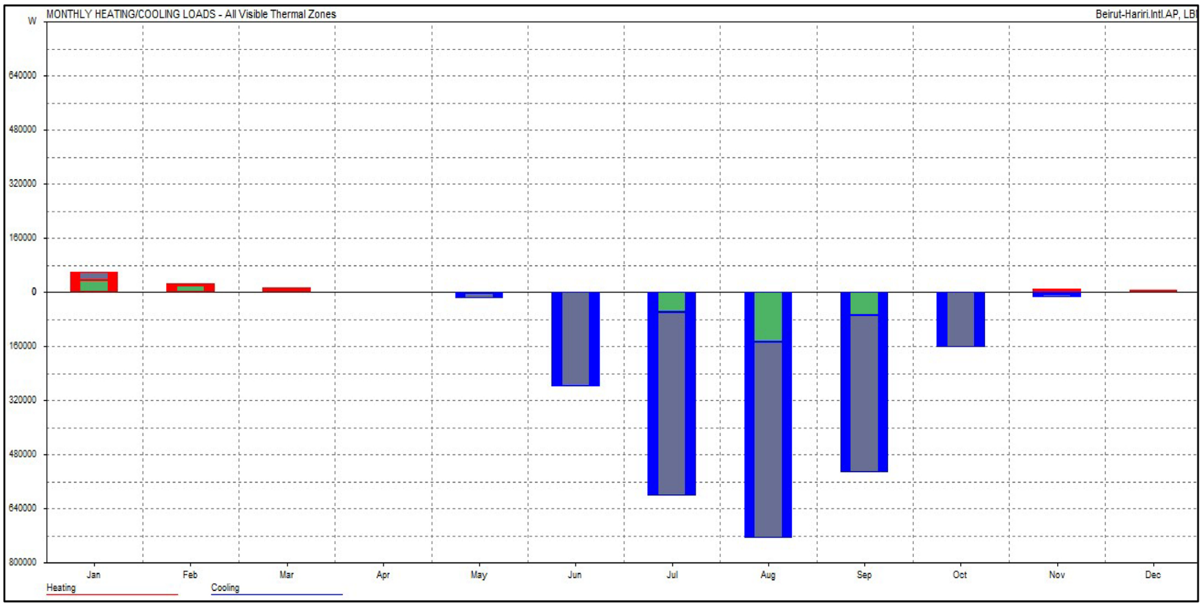


Figure 6. Annual heating and cooling load needed for the base case model in watts.

To know how to interact with the model and what improvement to do, we will check the passive gains breakdown graph in **Figure 7**. In order to evaluate the passive design strategies that will be studied, different analysis functions were used, mainly the ones related to passive gains. The first function used is Conduction loads through the fabric; these loads refer only to the gains due to differentials in air temperature between inside and outside the space. The second function used is Indirect solar loads through opaque objects, which refers to additional gains due to the effects of incident solar radiation on the external surface of exposed opaque objects.

The solar radiation acts to raise the external surface temperature which in turn increases the conducted heat flow. Also, Direct solar gains through transparent objects is a function used to analyze the effectiveness of passive strategies; these loads refer to solar radiation entering the space through a window.

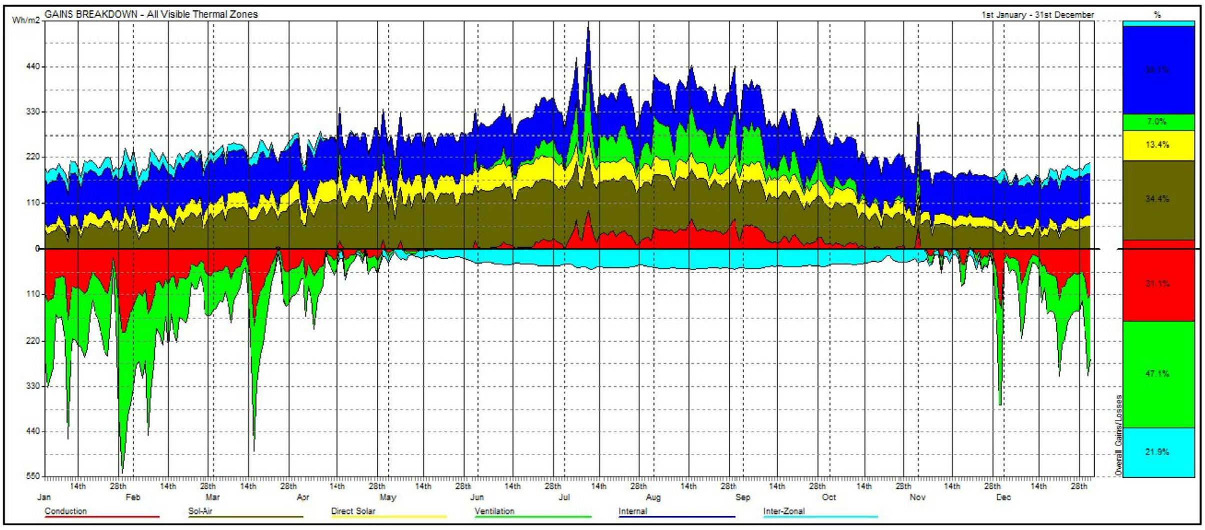


Figure 7. Passive gains breakdown of base case model in Wh/m^2.

3.2. Optimized Model

Many fundamental parameters for the passive design concept will be studied to evaluate their function and role on different passive design strategies.

3.2.1. Orientation and Room Arrangement

The orientation of the house influences cooling and ventilation load. The natural ventilation flow rate that is needed for passive cooling during hot season which constitutes 5 months of the year. A range of orientations has been modelled and tested using Ecotect weather tools to determine the best orientation of the house in terms of heating and cooling loads.

Simulating the different orientations showed that the best orientation is to have the longest facade with more window/wall ratio facing north (192.5˚ angle) as in **Figure 8**, in order to minimize the solar gains during hot season. Results are presented in **Table 4**.

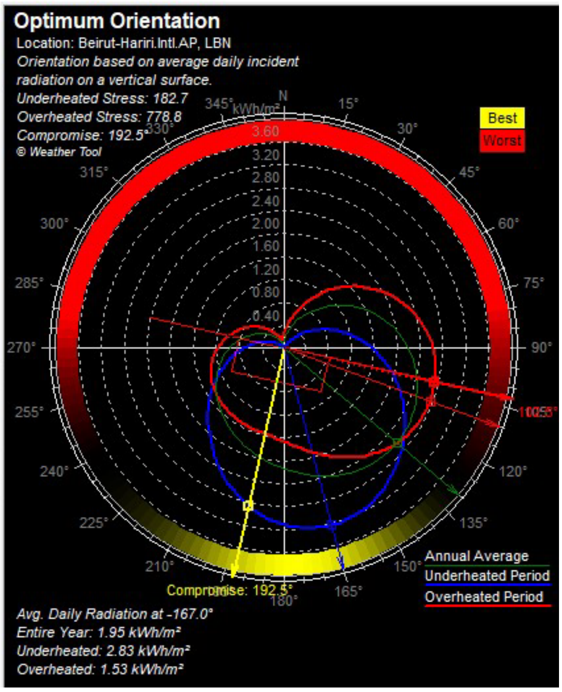


Figure 8. Best orientation for the base case model.

A study done in residential estate planning in 2013, in a climate similar to our base case conditions, Nanjing in China, Ma'anshan belongs to hot-summer and cold-winter region [18].

Table 4. Orientation performance summary.

Degrees	Heating Load (KWh/m^2)	Cooling Load (KWh/m^2)	Total Load (KWh/m^2)
0	1.68	27.25	28.93
30	1.77	25.22	26.99
90	1.78	23.86	25.81
150	1.64	25.89	27.53
180	1.54	27.26	28.80

3.2.2. Envelope

Different elements of the envelope were studied, such as walls, slabs, roofs and glazing. Each having many alternatives, using Ecotect software, we were able to identify the best option resulting in the lowest cooling load.

In our case, we will choose option W1 from Table 5 since material are available in market, in order to achieve better load optimization.

The slab doesn't have much impact on the heating and cooling loads, so we will pick an alternative consisting of 10cm concrete floor on top of 1.5 m soil + parquet 5 cm, with a total load of 28.73 KWh/m^2.

A small improvement in roof will lead to a high saving in cooling load since it is the most Exposed to solar radiation and receives huge solar heat. We will adopt

R2 from **Table 6**, since material are available in the market considering better improvement in terms of cooling loads.

Table 5. Envelope: wall performance.

Wall nb.	Description	Heating Load (KWh/m^2)	Cooling Load (KWh/m^2)	Total Load (KWh/m^2)
Base case W0	Hollow block 15cm thick with 1.5 cm thick plaster both sides	1.68	27.25	28.93
w1	10 cm double walls with 4cm air gap	1.54	26.21	27.75
w2	double brick with solid plaster	1.68	27.22	28.90

Table 6. Envelope: Roof performance.

Roof nb.	Description	Heating Load (KWh/m^2)	Cooling Load (KWh/m^2)	Total Load (KWh/m^2)
base case R0	15 cm concrete slab + 6 mm asphalt cover + plaster 1 cm	1.68	27.25	28.93
R1	15 cm concrete slab + 1 cm plastering	1.85	28.49	30.34
R2	15 cm concrete slab + PU rubber 5 cm + 1 cm plastering	1.28	23.93	25.21

3.2.3. Glazing and Shading

Glazing and shading are critical in passive design strategies since they have a high-impact on both passive heating and passive cooling of the building. Double-glazing window with different thicknesses of panels and air void has been studied and the output was very remarkable.

Moreover, different shading element proportions have been modelled and tested to control direct solar gains during hot season to avoid increasing thermal storage and undermining the effect of this setting is related to the wind speed and direction by a parameter defined as wind sensitivity used in the thermal simulation of natural ventilation that is used to passively cool the house.

Option G1 will be adopted from **Table 7** since the difference from other types is considerable, and will help achieve our target related to load demand optimization.

Table 7. Window performance.

Window nb.	Description	Heating Load (KWh/m^2)	Cooling Load (KWh/m^2)	Total Load (KWh/m^2)
G0	single glazed, aluminum frame	1.68	27.25	28.93
G1	double glazed with 6 mm air gap and low E coat, timber frame	1.70	22.79	24.49
G2	double glazed with 6mm argon gap and low E coat, timber frame	1.52	24.68	26.20

Adding shading element as overhang for west façade windows which will receive the most solar direct + diffusion radiation, as shown in **Figure 9**, will help reduce the cooling needed from base case model 27.25 Wh/m^2 to 23.73 Wh/m^2

while heating load will almost remain the same at 1.61 Wh/m^2.

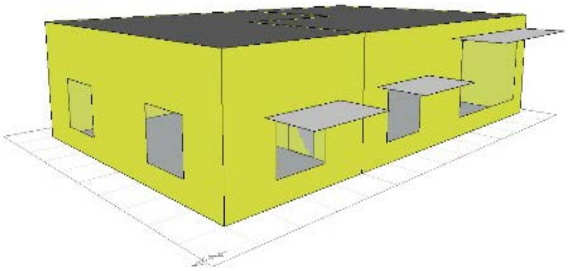


Figure 9. Shading design for west facing windows.

3.3. Model Summary and Comments

Based on the alternatives simulated previously, we will combine the best options of each case to get the best model in term of passively reducing energy consumption.

Combination of best alternatives without shading devices will give a space load of 17.63 KWh/m^2 (**Table 8**), representing a reduction of 39% from the base case model, which is remarkable.

Adding the impact of shading devices will improve the reduction to 46.4%.

Simu$_{\text{lat}}$ion results of best-case model are shown in **Figure 10**, while the passive gain breakdown of the optimized model is presented in **Figure 11**.

Comparing the passive gains breakdown will show a reduction in the red color related to conduction and yellow color related to direct solar gains, which is logical due to the improvement applied for the envelope including insulation, glazing with shading and best orientation.

Table 8. Best model space loads in Wh

Month	Heating (Wh)	Cooling (Wh)	Total (Wh)
Jan	52,545	-	52,545
Feb	24,968	-	24,968
Mar	12,793	-	12,793
Apr	-	-	-
May	-	10,722	10,722
Jun	-	184,605	184,605
Jul	-	421,652	421,652
Aug	-	532,043	532,043
Sep	-	379,894	379,894
Oct	-	114,748	114,748
Nov	7,866	14,303	22,169
Dec	7,800	-	7,800
TOTAL	105,973	1,657,966	1,763,939

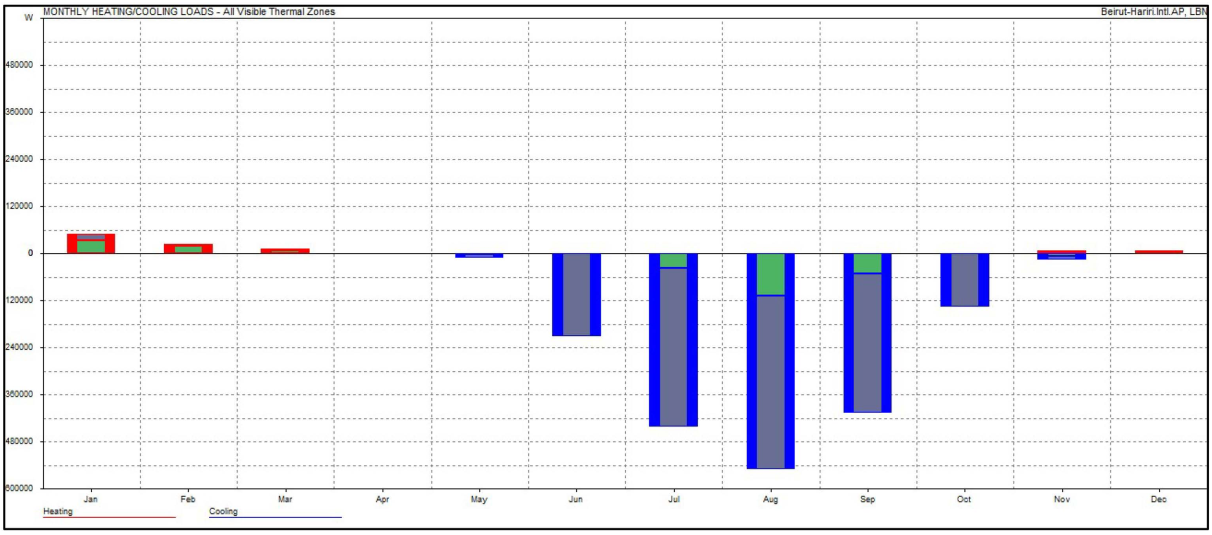


Figure 10. Best model adopting all alternatives.

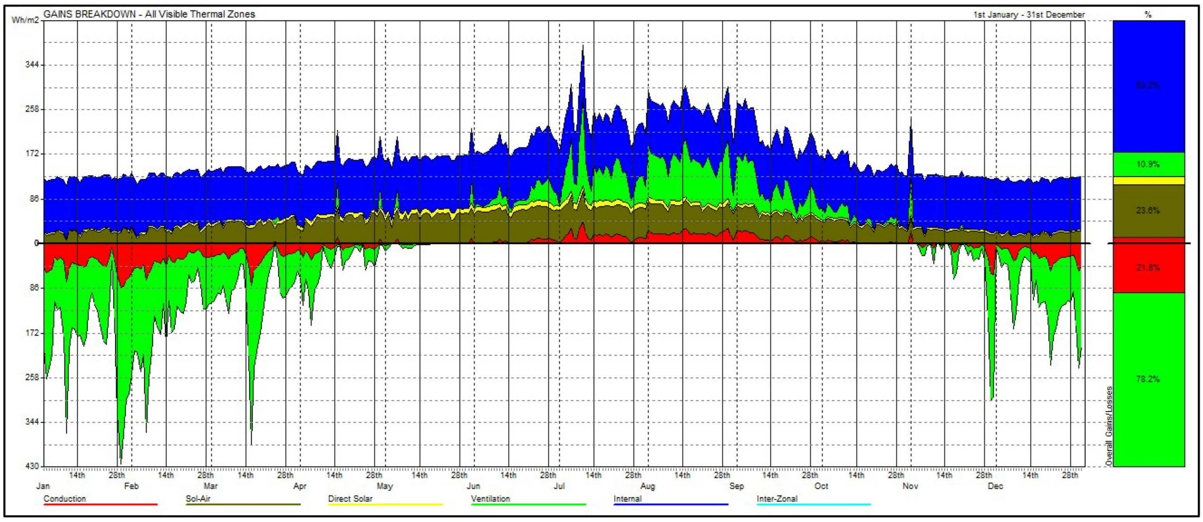


Figure 11. Passive gains breakdown for the best model.

As a percentage of total energy saving, as stated above, on average 40% of all energy consumed by buildings worldwide is used for space heating and cooling, we get 0.464 × 0.4 = 0.185 meaning that about 18.5% of the total energy bill of a house.

To calculate financial savings, assuming the cost of 1 KWh on average is 0.22$ [27], and average annual electricity consumption per capita in Lebanon is 3,495.68 KWh [28], and we have 3 habitants in the apartment, we get: 3495.68 × 3 × 0.22 × 0.185 = 426 $ of total annual saving, which is remarkable.

3.4. Renewable Energy Application: Solar Photovoltaic Panels

After discussing different passive design strategies in order to achieve the maximum energy reduction to our base case model, we will focus on using renewable energy system to cover the remaining energy needed, notably the solar photovoltaic panels system.

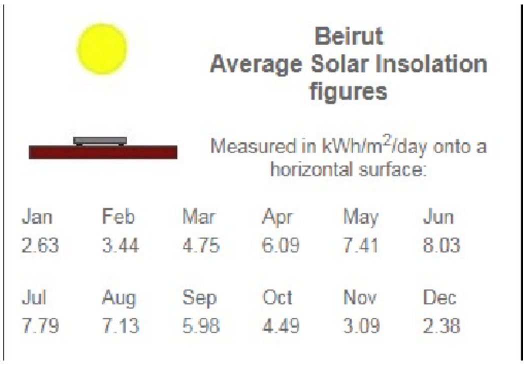
Solar photovoltaic systems generally consist of six individual components: the solar PV array, a charge controller, a battery bank, an inverter, a utility meter, and an electric grid. The correct installation of all of these components determines how efficient the solar panels are. However, a charge controller and battery bank are optional.

In order to determine the total electric power needed on annual basis, we will consider that the building is using efficient lighting appliance and electric equipment. The equipment and systems with their corresponding electric power consumption that are taken into consideration are shown in Table 9.

Table 9. Annual power consumption of base case model (kwh/year).

S/N	Appliance	Quantity	Watts	Operation (Hours per Day)	Watt x Hours	KWh/Year
1-	Lampe 1	3	10	6	180	65.7
2-	Lampe 2	6	15	4	360	131.4
3-	Television	2	40	5	400	146.0
4-	Refrigerator	1	230	14	3220	1,175
5-	Freezer	1	100	16	1600	584.0
6-	Washing machine	1	600	3	1800	657.0
7-	dryer/ ironing	1	1650	1	1650	602.3
8-	phone/laptop charger	2	15	4	120	43.8
9-	WI-FI router	1	10	24	240	87.6
10-	Pump	1	800	1	800	292.0
11-	Microwave or stove	1	1200	0.5	600	219.0
12-	Space cooling and heating					1,512
						5516.8

To design the PV system in a way to cover all the building's annual energy needed, we will use an average per day of: 5,516/365 = 15.1 KWh/day.



Jan	Feb	Mar	Apr	May	Jun
2.63	3.44	4.75	6.09	7.41	8.03
Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
7.79	7.13	5.98	4.49	3.09	2.38

Figure 12. Solar irradiation in Lebanon [29].

The average solar insolation of the building under study 5.2 KWh/m^2/day is shown in **Figure 12**.

To estimate the electricity generated by a photovoltaic system, we will use the following formula:

$$E = A \times r \times H \times PR \quad [30] \tag{1}$$

Where: E = energy (KWh);

A= total area of solar panels (m^2);

r = solar panel yield (%);

H = annual average solar radiation on tilted panels;

PR = performance ration, coefficient for losses.

In our case, using 8 PV module Longi LR5-72HPH of 545 w, we have:

A = 2.2 × 1.1 = 2.42m^2; r = 21.3%; PR = 0.8; Average daily solar radiation = 5.2 KWh/m^2 We get E = 8 × 2.42 × 0.213 × 5.2 × 0.8 = 17.15 KWh/day > 15.1 KWh/day.

So, we will use 8 panels of Longi LR5-72HPH.

For the battery bank calculation, we will assume that we need backup system for 24 hours, and we need the system to produce 4A, so the total power needed will be: 4 × 24 × 220 = 21,120 Wh.

Using losses factors of 80% for DOD and 60% for total discharge [30] and using a system of 48 V, size needed will be a follow:

$$\frac{Power}{Loss\ x\ DODpower\ x\ System(V)} \tag{2}$$

Applying the formula, we will get: $\frac{21120}{0.8 \times 0.6 \times 48} = 916.6A$; so, we will use 5 batteries of 200 A each.

For the inverter size, since the system is 48 V and we have a system of 4360 w (8 × 545), we will choose an inverter of 5 Kva and 48 V. We are using a system of 8 × 545/20 = 19.1 A and 48 V, so the charge controller will be of 20 A and 48 V.

System cost: We will use price from Lebanon market to approximate the cost of the system.

8 panels of 545 W are at 8 × 100 = 800 $.

5 batteries of 200 A are at 5 * 180 = 900 $.

Inverter 5 Kva and 48 V is at 350 $.

Combiner box with charge controller, wires, utility meter, chassis for panels and workmanship will cost about 800 $.

So, the total cost of the system will be 2850 $.

4. Conclusions

The year-round fresh indoor air quality and stable temperature, the substantial reduction in energy use and operating costs, and the quiet atmosphere that the Passive House standard delivers are directly attributable to the NZEB principles and the way they are integrated into a Passive House building.

Architects and designers should give full consideration to various ecological energy-saving methods in the concept design. Buildings must become more ecological, consume less energy, and ultimately create a better living environment.

By building NZEBs instead of conventional ones, energy for buildings can be generated by the building itself and can reduce the energy crisis, and the country's environmental emissions.

This project explored how net-zero energy and passive design strategies can be implemented. A huge reduction has been noted in the required heating and cooling loads, from 28.94 KWh/m^2 to 17.63 KWh/m^2, consisting of 39% for a typical 100 m^2 located in Beirut, by adopting simple passive design strategies, like upgrading the windows from single pane to double pane, applying insulation in roof and walls, orienting the building in correspondence to required passive heating or cooling reduction, and implementing shading devices to control solar exposure of the building.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author, F.B, upon reasonable request.

Conflicts of Interest

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

References

[1] National Geographic: Climate Change. https://nationalgeographic.org

[2] The Built Environment, Architecture 2030 Why The Built Environment. https://www.architecture2030.org/why-the-built-environment/

[3] MoE/UNDP/GEF (2017) Lebanon's Second Biennial Update Report to the UNFCC, Beirut, Lebanon.

[4] Pătrașcu, G. (1984) Arhitectura și tehnicapopulară (Folk Technique and Architecture). Editura Tehnică.

[5] Jaysawal, R.K., Chakraborty, S., Elangovan, D. and Padmanaban, S. (2022) Concept of Net Zero Energy Buildings (NZEB)—A Literature Review. *Cleaner Engineering and Technology*, **11**, Article ID: 100582. https://doi.org/10.1016/j.clet.2022.100582

[6] Jones, G.G. and Bouamane, L. (2012) 'Power from Sunshine': A Business History of Solar Energy. Harvard Business School Working Paper Series.

[7] Vale, B. and Vale, R. (1975) The Autonomous House: Design and Planning for Self-Sufficiency. Universe Books.

[8] Ionescu, C., Baracu, T., Vlad, G., Necula, H. and Badea, A. (2015) The Historical Evolution of the Energy Efficient Buildings. *Renewable and Sustainable Energy Reviews*, **49**, 243-253. https://doi.org/10.1016/j.rser.2015.04.062

[9] Stahl, W., Voss, K. and Goetzberger, A. (1994) The Self-Sufficient Solar House in Freiburg. *Solar Energy*, **52**, 111-125. https://doi.org/10.1016/0038-092x(94)90085-g

[10] Iqbal, M.T. (2004) A Feasibility Study of a Zero Energy Home in Newfoundland. *Renewable Energy*, **29**, 277-289. https://doi.org/10.1016/s0960-1481(03)00192-7

[11] Kilkis, S. (2007) A New Metric for Net-Zero Carbon Buildings. *ASME* 2007 *Energy Sustainability Conference*, Long Beach, 27-30 July 2007, 219-224. https://doi.org/10.1115/es2007-36263

[12] Laustsen, J. (2008) Energy Efficiency Requirements in Building Codes, Energy Efficiency Policies for New Buildings. IEA Information Paper.

[13] Noguchi, M., Athienitis, A., Delisle, V., Ayoub, J. and Berneche, B. (2008) Net Zero Energy Homes of the Future: A Case Study of the EcoTerra™ House in Canada. *Renewable Energy Congress*, Glasgow, 19-25 July 2008.

[14] Berardi, U. (2018) ZEB and nZEB (Definitions, Design Methodologies, Good Practices, and Case Studies). In: Desideri, U. and Asdrubali, F., Eds., *Handbook of Energy Efficiency in Buildings*: *A Life Cycle Approach*, Butterworth-Heinemann, 88.

[15] Tibi, G., Ghaddar, N. and Ghali, K. (2012) Sustainable Design Guidelines for Detached Housing in the Lebanese Inland Region. *International Journal of Sustainable Built Environment*, **1**, 177-193. https://doi.org/10.1016/j.ijsbe.2013.06.001

[16] Caulfield, J. (2017) Exponential Growth in Net Zero Energy Buildings Predicted for the Next Two Decades. Energy Efficiency. https://www.bdcnetwork.com/home/news/55160630/exponential-growth-in-net-zero-energy-buildings-predicted-for-the-next-two-decades

[17] Attia, S. (2018) Net Zero Energy Buildings (NZEB): Concepts, Frameworks and Roadmaps for Project Analysis and Implementation. Elsevier.

[18] Yang, L., He, B. and Ye, M. (2014) Application Research of ECOTECT in Residential Estate Planning. *Energy and Buildings*, **72**, 195-202. https://doi.org/10.1016/j.enbuild.2013.12.040

[19] (2010) Thermal Standard for Buildings in Lebanon. https://docslib.org/doc/6393707/thermal-standard-for-buildings-in-lebanon-2010

[20] https://climate.onebuilding.org/WMO_Region_6_Europe/LBN_Lebanon/LBN_BA_Beirut-Hariri.Intl.AP.401000_TMYx.2009-2023.zip

[21] Chaaban, F. and Rahman, S. (1998) Baseline Energy and Electricity Consumptions in Lebanon and Opportunities for Conservation. *Energy Policy*, **26**, 487-493. https://doi.org/10.1016/s0301-4215(98)00011-1

[22] Nationmaster (2003) Lebanon Energy Ranking. https://www.nationmaster.com/country-info/profiles/Lebanon/Energy

[23] Chedid, R., Chaaban, F. and Salameh, S. (2001) Policy Analysis of Greenhouse Gas Emissions: The Case of the Lebanese Electricity Sector. *Energy Conversion and Management*, **42**, 373-392. https://doi.org/10.1016/s0196-8904(00)00060-1

[24] ESCWA (2001) Improving the Efficiency of Energy Use in the Buildings Sector.

[25] (2008) Republic of Lebanon: Electricity Sector Public Expenditure Review. Report No. 41421-LB. World Bank.

[26] Mourtada, A. (2016) Energy, Climate Change and the Building Sector in the Mediterranean: Regional Prospects Report. https://www.researchgate.net/publication/268408852_Energy_Climate_change_and_the_Building_sector_in_the_Mediterranean_Regional_Prospects_Report

[27] World Data with Info: Energy Consumption in Lebanon. https://www.worlddata.info/asia/lebanon/energy-consumption.php

[28] Lebanon Electricity Consumption. https://countryeconomy.com/energy-and-environment/electricity-consumption/lebanon

[29] Solar Irradiance in Lebanon.
https://www.researchgate.net/figure/Solar-irradiance-in-Lebanon-Source-12-Multiplying-the-monthly-average-solar_fig3_349158365

[30] How to Calculate the Annual Solar Energy Output of a Photovoltaic System?
https://photovoltaic-software.com/principle-ressources/how-calculate-solar-energy-power-pv-systems