ENERGETIKA. 2022. T. 68. Nr. 1. P. 43–67

Energy-passive residential building design in Amman, Jordan

Renad Wael Albadaineh

German Jordanian University
Naji Alhabashneh, 11937, Jordan
Email: renadaabadayneh@gmail.com

In Jordan, the residential sector is responsible for 43% of all power use and 21% of total energy usage. The use of energy for space heating and cooling accounts for more than 60% of residential energy use. The computer-generated residence, a typical one-storey Jordanian home with a functional floor area of 186 m^2, is located in Amman and was modelled to be more energy efficient by incorporating renovating techniques to lower heating and cooling demand, attain marginal energy demand, and produce a high-quality indoor living environment. To get at the idea of passive design houses as appropriately depicted in this paper, various passive design tactics and methodologies were employed. Using DesignBuilder simulation software, Revit modelling software, solar energy analysis software, and assessment of the total energy consumption before and after the deployment of passive design approaches, the effects of each retrofit method were evaluated. The results of this study show that the yearly energy savings for heating is about 78%, and the indoor air quality and temperature of the residence can be significantly enhanced compared to its original situation. The total employed energy in the virtual building was scaled down from 56.57 kWh/m^2 to 15.25 kWh/m^2 each year.

Keywords: low carbon buildings, passive house design strategies, energy efficiency, thermal simulation, building energy performance, zero energy buildings

INTRODUCTION

Residential and public buildings become the biggest energy consumer, with nearly 60% of the overall energy consumed in Jordan [1]. Compared to the energy used in transport and industry, more energy is consumed in the residential sector, and it indicates a considerable opportunity to reduce energy use and restrict carbon dioxide emissions. Figure 1 shows the sectoral consumption of electric energy during the period of 2016–2020: electric consumption for the residential sector increased during the period of 2016–2020, while the consumption of the industrial sector clearly decreased. On the other hand, the commercial and agricultural sectors increased and decreased during the mentioned years.

According to the statistical data from the Jordanian Department of Statistics, the national average usable floor area is 125 m^2 and the average household energy consumption was 7963 GWh in 2018 [2]. Energy performance levels of the existing Jordanian building stock are much lower than the requirements of the local Energy Efficient Building Code.

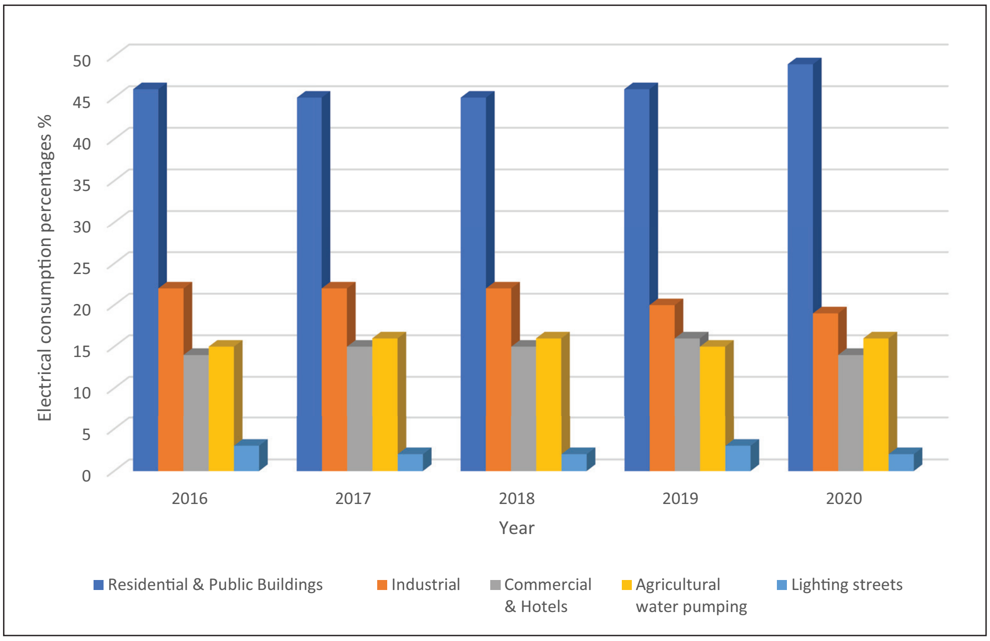
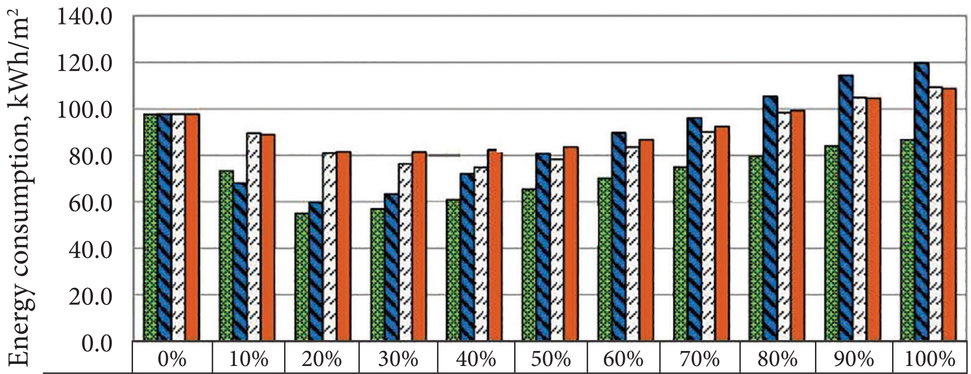


Fig. 1. Sectoral consumption of electric energy during the period of 2016–2020 [1]

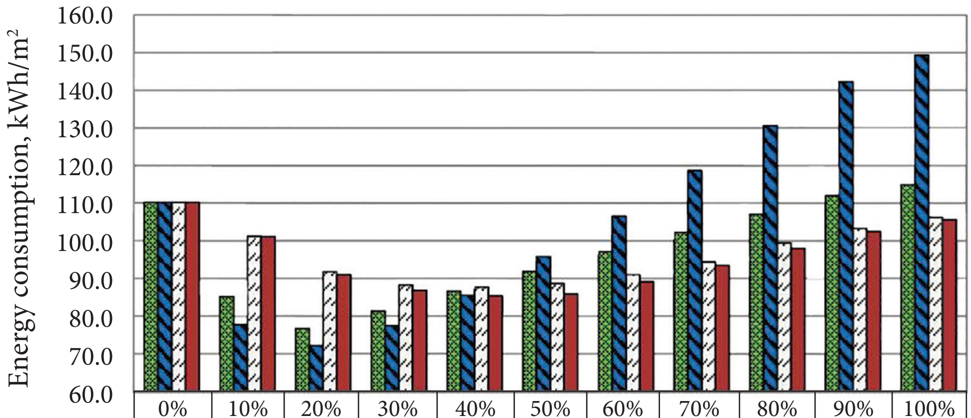
LITERATURE REVIEW

Our study uses an analytical approach that depends on DesignBuilder v.6.1.5.004 program. DesignBuilder is a famous program that has been used in many studies since it can analyse multi-objective energy performance in one building or a set of buildings. And it is GUI (graphical user interface) software program that allows extra flexibility on geometry inputs and has large fabric libraries and load profiles. The inputs for the simulation version are constructing version, usage pattern, and hourly weather information. The energy intake required for the running of diverse loads is calculated on an hourly basis DesignBuilder allows complex buildings to be modelled in a simple fast way even by non-expert users. Also, it is the first and most comprehensive program that creates a graphic interface to an EnergyPlus dynamic thermal simulation engine; it uses the latest model of the EnergyPlus simulation engine for calculating the energy performance of buildings. The resulting records can be filtered as desired and presented in graphs or may be exported in a tabular layout to be used in different applications [5]. Jalil Shaeri determined the optimal window-to-wall ratio; the DesignBuilder tool was used to evaluate the yearly solar heat gain, the cooling load, the heating load, and the lighting demand as shown in Figure 2, and to uniform the research for three Iranian cities of Bushehr, Shiraz, and Tabriz. The solar heat gain, the cooling load, the heating load, and lighting usage of the building were estimated in unique stats for each of the three climate zones. According to ASHRAE standards, all software variables were tuned to promote thermal comfort and energy efficiency. It was discovered that windows with window percentages of 20–40% on the north elevation of the building consumed the least energy [6].

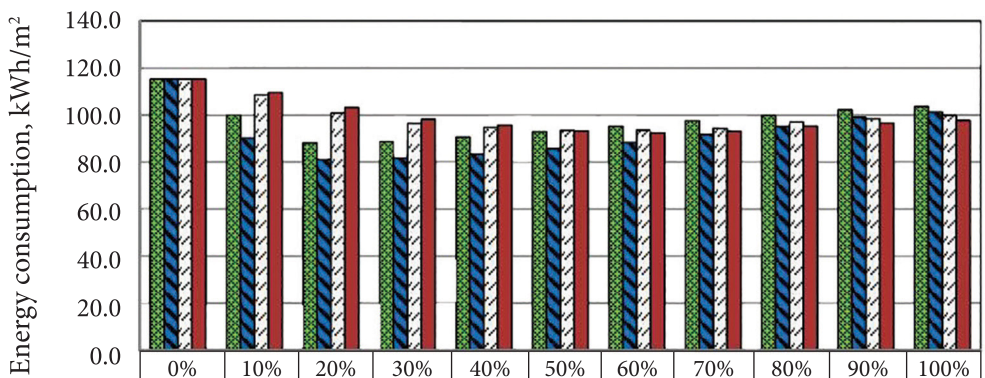
The study also used Revit 2020 program. The major strengths of the tool are its visual appearance and suitability for early stages of design. However, it displays a lack of accuracy and reliability in thermal analysis. Also, too many options and too much information are incorporated. Another study by Xinxin Lianga tested the functionality of a traditional residence, and a passive house in North-East England was tracked over the course of a year using DesignBuilder software to examine the effectiveness of the system between the two types of homes in the UK. These two buildings had divergent thermal performance and indoor air quality due to variances in their building materials, methods of ventilation and thermal storage, energy use, and inhabitant occupancy. The measurement



	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
North	97.7	73.3	55.0	56.8	60.9	65.5	70.2	75.0	79.6	84.1	86.8
South	97.7	68.1	59.7	63.4	72.0	80.8	89.7	96.1	105.4	114.4	119.8
East	97.7	89.5	81.0	76.3	74.9	78.3	83.5	90.1	98.4	104.9	109.4
West	97.7	88.9	81.5	81.3	82.3	83.6	86.8	92.4	99.3	104.6	108.8



	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
North	110.3	85.2	76.7	81.4	86.6	91.9	97.1	102.2	107.1	112.0	114.9
South	110.3	77.1	72.2	77.5	85.6	95.8	106.5	118.7	130.5	142.2	149.3
East	110.3	101.2	91.8	88.2	87.7	88.7	91.1	94.4	99.5	103.3	106.2
West	110.3	101.2	91.0	86.8	85.4	85.9	89.1	93.5	98.0	102.5	105.6



	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
North	115.3	100.1	88.2	88.7	90.6	92.8	95.2	97.6	100.0	102.3	103.7
South	115.3	90.1	81.1	81.7	83.3	85.6	88.4	91.7	95.1	99.0	101.3
East	115.3	108.6	100.9	96.5	94.7	93.5	93.6	94.4	97.1	98.5	99.8
West	115.3	109.6	103.2	98.2	95.7	93.2	92.4	93.2	95.3	96.5	97.6

Fig. 2. Annual total cooling, heating, and lighting loads per m² of buildings with different percentages of windows at different facades in Bushehr (top), Shiraz (middle), and Tabriz (bottom), Iran [6]

data show that the traditional house and the passive house had initial energy demands of 169.85 kWh/(m²·a) and 64.11 kWh/(m²·a), respectively, while maintaining yearly average internal temperatures of 17.7°C and 22.0°C, respectively [7]. The purpose of this research was to find out the differences in the energy behaviour of a structure between the base building given (without retrofits) and the passive building (modified building with retrofits) in Amman, Jordan, and to investigate the potential measures to improve the building performance by applying passive power-saving retrofitting strategies. To accomplish that, the DesignBuilder simulation was used to understand the behaviours of each building.

METHODOLOGY

The baseline model

The basic design is shown in Fig. 3, which is comprised of three bedrooms, a living room, a kitchen, a guest room, bathrooms, and a storage room. Table 1 lists the design requirements and features of the case study building. Our goal is to use diverse approaches, which are discussed below, to enhance the thermal properties of the construction elements of the building and make it a passive house design.

Table 1. **Basic design features**

The building construction properties	Baseline model
Number of storeys	1
Overall storey area	186 m²
Number of spaces	9
External walls (U-value)	0.563 W/m²·K
Internal walls (U-value)	2.5 W/m²·K
Roof (U-value)	0.535 W/m²·K
Ground floor (U-value)	1.877 W/m²·K
Window frame type	Aluminium frame with polyvinyl chloride (PVC), 5.014 W/m²·K
Glazing type + U-value	Double glazing with 3.094 W/m²·K

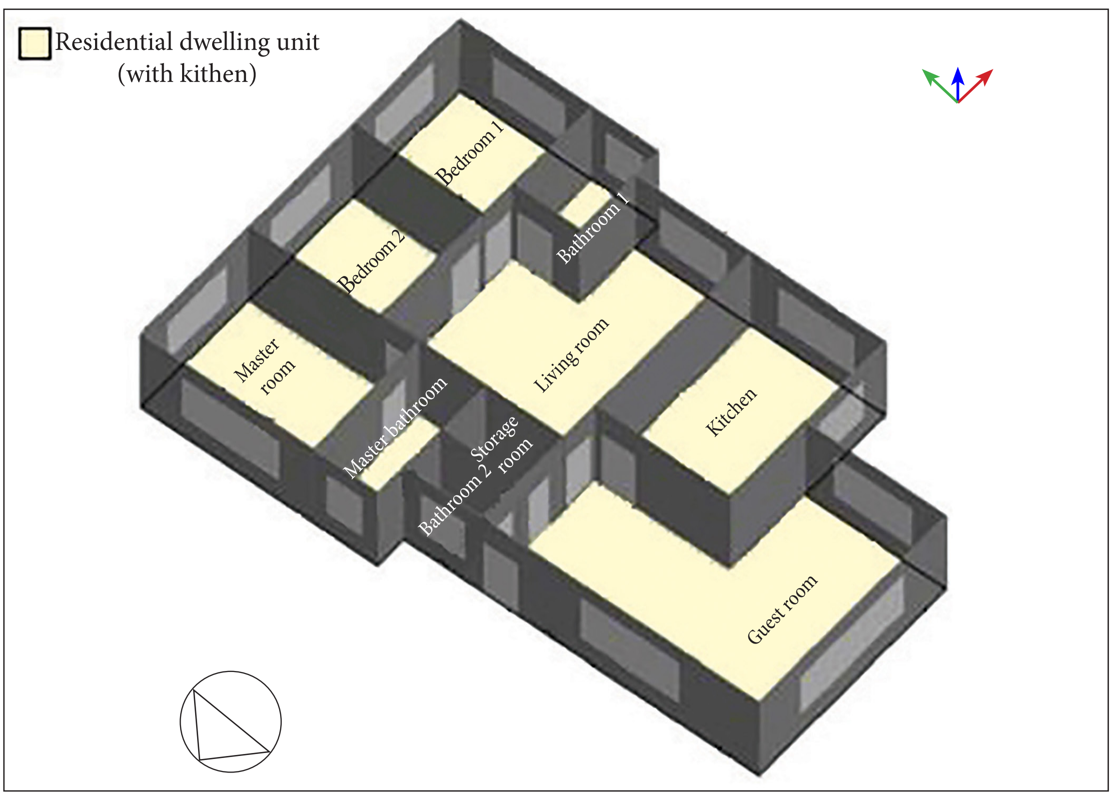


Fig. 3. A 3D shot of the basic design model

Climate analysis

According to Köppen's climate classification in the atlas of Jordan [25], Jordan is divided into six climatic zones. As shown in Fig. 4, it is characterised by aridity, temperate, and dry summer. The climate of Jordan is affected by the country's location between the dry quasi-tropical climate of the Arabian Desert and the subtropical humidity of the eastern Mediterranean. The country's climate zones can be classified into three major geographical zones that are divided laterally by the Thermal Insulation Code [26], the Rift Valley in the west; the eastern highlands in the east; and the parched desert. The fertile Rift Valley extends to Aqaba and spans the length of Jordan's western area at an elevation less than 600 metres.

Amman, Jordan, is characterised by warm summers and cold winters. The climate varies dramatically between day and night, in addition to between the summer and winter seasons. Summers are warm, dry, and windy, and temperatures can exceed 40°C, while winters can be bitterly cold, humid, and windy. This distinct version of climate within Jordan advocates for distinctive processes for energy-efficient buildings [3].

In Jordan, there are three main climate districts, and each calls for various design approaches. Amman, the capital, is in the Highlands Area and has hot and dry summers with chilly and rainy winters (35.88E, 31.96N). In January and July, the mean temperature varies from 8°C to 25.1°C. The warmest day of the year is in July with a high temperature of 39°C, while the coldest day of the year is in January with temperatures of 0°C. The passive house concept was described as smart buildings with very small heating energy demand but gain comfortable indoor environmental conditions and high-quality indoor air. Over 50,000 passive house systems were built around the world in 2013, because the passive house was established as one of the maximum leading energy-efficient residential constructions and applies to different climates [4]. The energy retrofit approach will assist the country to reduce energy utilisation in buildings, thus decreasing electricity costs on a large scale and enhancing Jordan's sustainable development.

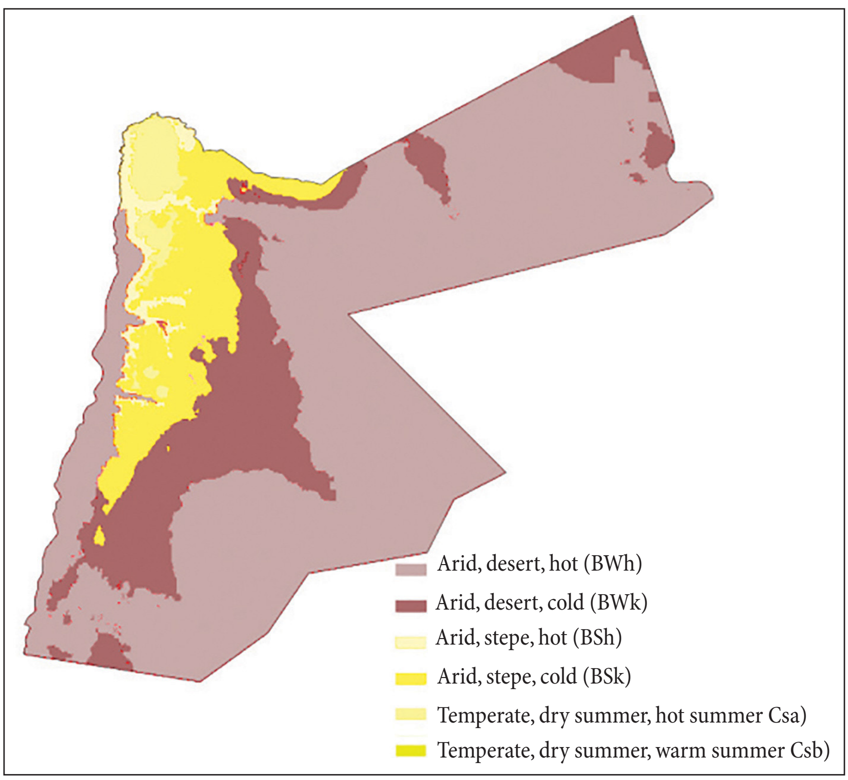


Fig. 4. Climate zones of Jordan (Source: present and future Köppen-Geiger climate classification maps at 1-km resolution. Nature Scientific Data) (Climate change in Jordan, 2016)

Weather simulation parameters

Considering that energy use is influenced by outdoor temperature, assessing environmental conditions is a crucial component of the planning and installation of energy systems. The monthly minimum and maximum values of temperature distribution are shown in Fig. 5. The highest temperature recorded annually is 32.4°C in August, and the coolest is 3.6°C in January [8]. According to the ASHRAE standard, the heating operating point in the building simulation was 18°C, and the cooling operating point was 27°C.

Air quality in the structure relies on the ventilation rate that brings clean air to the building. It is important to control indoor air quality (IAQ) for comfort, health, and for the sake of productive capacity. Due to the ASHRAE standard 62-2001, the rate of ventilation depends on the storey area of the structure, which means that for residential dwellings, the air changes per hour (ACH) should be about 0.35 ACH but not less than 7.5 l/s per person [9]. In our case, we selected the ACH rate as 8 l/s per person.

Design analysis and performance of the building through simulation

Energy efficiency of a building only increases when its inhabitants feel comfortable in their surroundings. The residents of the building evaluate the thermal comfort, which is described by the ASHRAE standard as 'a state of mind which indicates a fulfilment with the thermal conditions'. Therefore, we can only presume that parameters like air temperature, dampness, and airflow all rely on how everyone experiences these factors. An equilibrium between energy usage for heating or cooling in relation to the interior temperature, moisture levels, and airflow percentage is required to achieve thermal comfort in the building [9]. We must first consider the timetable of occupation to obtain a valid assessment of the energy demand needed by a passive dwelling. The research used a daily occupancy pattern of a home for four people, claimed thermal comfort when occupants were present, and cut heating energy use by 50% when the tenancy was nil. The simulation's year-long time frame is a two-hour period. The house is vacant from 9:00 AM to 5:00 PM, hence less energy is used during this time. The energy required for heating, which begins in October and lasts until the 1 April, was calculated by factoring in the U-value and the thickness of the envelope. For the entire 186 m^2 surface of the building, the overall energy requirement for heating in this scenario is 2170 kWh/year, or 15.25 kWh/m^2/year. Due to the excellent insulation of the house, the annual energy requirement is only 15.25 kWh/m^2.

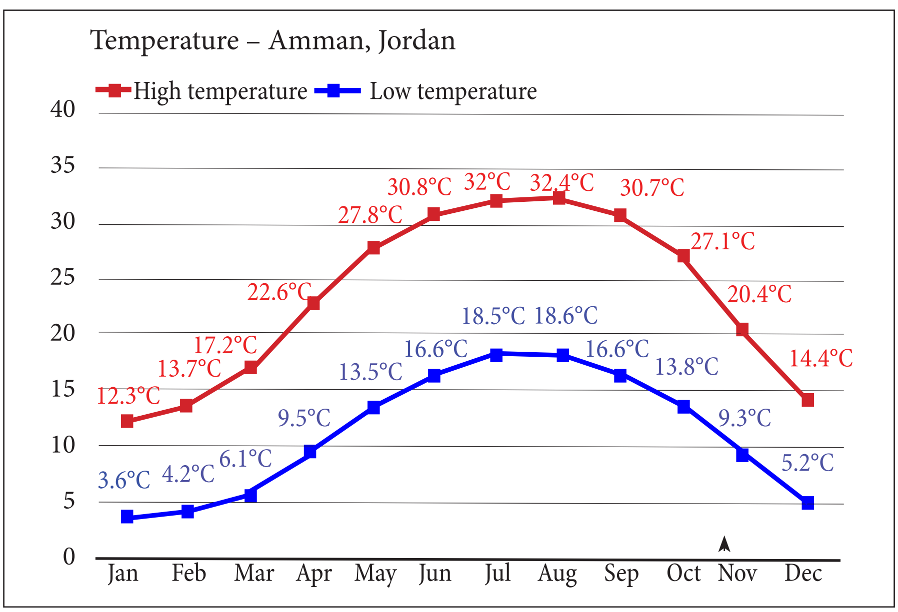


Fig. 5. Dispersion of monthly mean temperature

Under the conditions of maximum energy consumption, the surface area of the spaces and the occupied profile of the home is related to the interior and exterior temperatures. The measurement of the inside temperature ranges from 19°C to 26°C [9].

Simulation software

Autodesk Revit is a building information modelling software for architects and other engineers. The software allows users to design a building structure and its components in 3D, annotate the model with 2D drafting elements, and access building information from the building model database. Revit work environment allows users to manipulate the whole building or assemblies (in the project environment) or individual 3D shapes (in the family editor environment). Modelling tools can be used with pre-made solid objects or imported geometric models. In our developed design, we used Revit to create the building envelope, to analyse solar and shading effects on elevations, sections, and other drawings, and then we exported it using the extension of gbXML to simulate the energy performance on the DesignBuilder.

On the other hand, DesignBuilder is a simulation tool with enhanced energy inputs to meet accurate analysis data for a certain architectural design. One of the building modelling and simulation software used in this research was DesignBuilder. The EnergyPlus is the simulation engine, which is integrated into the DesignBuilder software and provides several features, including modelling, assessment, improvement, and environmental effect analysis [20]. DesignBuilder is probably one of the tools praised and rated among the best by architects and engineers. It is designed to execute EnergyPlus calculations on digital solid modelling and is used in this software to mimic heat transfer procedures, climatic factors, and other elements that affect energy usage in structures. EnergyPlus is a whole-building energy modelling application used by researchers and experts in the construction sector to estimate energy usage for heating, cooling, ventilation, lighting, and plug and process loads, as well as water consumption in structures [21].

The reliability and appropriateness of database software have been highlighted, particularly in relation to structure performance investigations [22]. Moreover, it is a three-dimensional, all-encompassing platform created on the foundation of EnergyPlus. EnergyPlus is designed to be a precise computation engine, leaving the creation of more user-friendly pre-and post-processing stages to other tools [23]. The interior and exterior of the residence, as well as the substances utilised in its design, were all recreated using DesignBuilder to create the final product. By multiplying the design parameters at specified circumstances for an unsteady factor 1, the hourly schedules of the simulation product for each thermal zone enable us to examine the hourly amounts of load volume of equipment, lighting, and the DWW need in a year. Because DesignBuilder software has rich data forms for a wide range of building simulation entries, such as conventional envelope building components, lighting fixtures, and occupancy schedules, it is ideal for use in building simulations. These frameworks are particularly appealing to newcomers who may not recognise when more precise inputs relevant to their building are required [24].

In our analysis, we determined the activity to ASHRAE building type 'Residential' with a heating source from electricity and solar gain, an occupied floor area of 113.75 m^2, and no electrical equipment used in the house. The building construction components are exterior and interior walls, flat roofs, and ground floors with certain layers of each component as mentioned in this report. Airtightness has a value of 0.7 ac/h according to passive-design houses with a good insulation criterion. The windows and frames are specified to meet a very low U-value with high thermal resistance by using argon gas between double glazing in the window and using UPVC frames with metal cladding to reduce heat transfer through them. A shading system with multiple devices and tools was implemented in the design; it will be explained later in this report. Lighting and HVAC systems that were used, LED for lighting with a minimum lux per room function, and HVAC systems were turned off because of the dependence on natural ventilation for cooling through summer days, and solar heat gain for heating through winter days.

Simulation and optimisation phases

To meet the passive house guidelines, there are five main requirements [12]:

1. A designated heating demand of less than 15 kWh/m^2.
2. A specific cooling demand of less than 15 kWh/m^2.
3. The exact primary energy demand, including electronic devices, is less than 120 kWh/m^2.
4. Airflow cannot be greater than 0.6 ac/h.
5. Clean air consumption 30 m^3/h/person.

Design methods included in our suggested design to fulfil the passive house standard:

1. High insulation.
2. Thermally sealed windows.
3. Passive solar gain.
4. Design, legislation, and inclination.
5. Sustainably sourced ventilation techniques.
6. Making use of shading tools.

Building form and aspect ratio

The facility's geometry, which is a significant element in heat gain and loss, has an impact on the energy efficiency of the building. It is determined by geometrical components like the ratio of the building length to width in the plan and the height of the building. The aspect ratio of a structure is one of the most significant factors of energy efficiency, and there is a clear connection between the design and the energy performance of a facility. It specifies the amount of the total area of the building that is subject to solar gain and the percentage of the total area of the building by which heat is exchanged between the interior and exterior environments. The rectangular shape with an aspect ratio of 1:1.3 or 1:1.7 performs the best. As described in Fig. 6, the developed design is divided into three parts: each part presents a perfect aspect ratio for energy efficiency performance [11, 13].

Orientation

The building should be oriented in such a way as to benefit from the sun and wind according to the climatic conditions in the region of simulation. Thus, orientation is a sustainable design element that is required at the earlier stage of the architectural design, which can result in an 82% reduction in heating and cooling loads. Our proposed design aimed at orienting the long axis of the building towards the south elevation to maintain the maximum solar exposure during the day through the winter season and can be easily shaded during the summer season. As shown in Fig. 7, image (a) is taken at noon on 1 June, when the sun is high, while image (b) is taken at noon on 1 December where the sun is low. On the northern and southern sides, solar radiation is lower than on the eastern and western sides. Therefore, the preferred building orientation is along the east-west axis with minimisation in the length of the western and eastern sides as it is explained in the building form section. Besides the whole building orientation, it is

Fig. 6. The building aspect ratio is divided into three parts

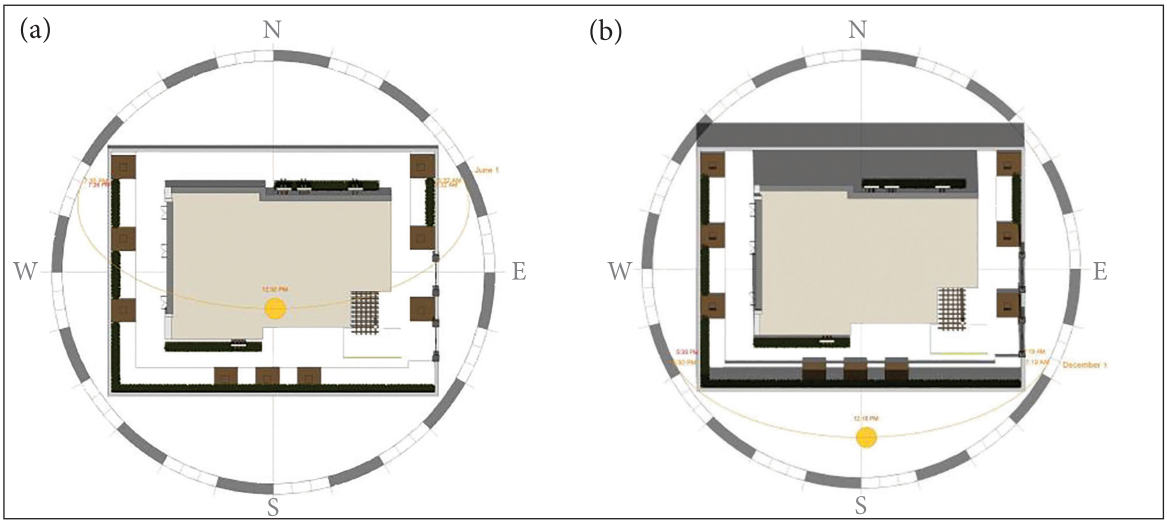


Fig. 7. Orientation of the optimised building with the long axis facing the south-north elevation in the (a) summer and (b) winter seasons

necessary to direct rooms in the internal layout according to their function towards their need for sufficient daylight, natural ventilation, heating, and cooling demand in terms of reducing energy consumption [14].

Zoning and planning

The layout of the architectural plan of the passive house should consider multiple constraints at the first stage of zoning and planning to get the minimum heat gain in the summer season and the maximum heat gain in the winter season. To minimise energy requirements of the building, the internal layout of the design, thermal zoning, the concept of articulation, and stratification of zoning depending on buffer zones, sanitary spaces, lighting levels, and heating needs [13]. To articulate architectural elements is to clearly distinguish the parts that form the whole layout, especially at the points of their connection. Locate rooms that have a similar function (heated/unheated) together to minimise heat loss through internal layout and zone the building according to uses with different room temperatures [15]. In our proposed design, we have the following functions that are integrated into the architectural plan, as shown in Fig. 8. The specified spaces were categorised into three categories: private, semi-private, and public zones [13, 16, 17].

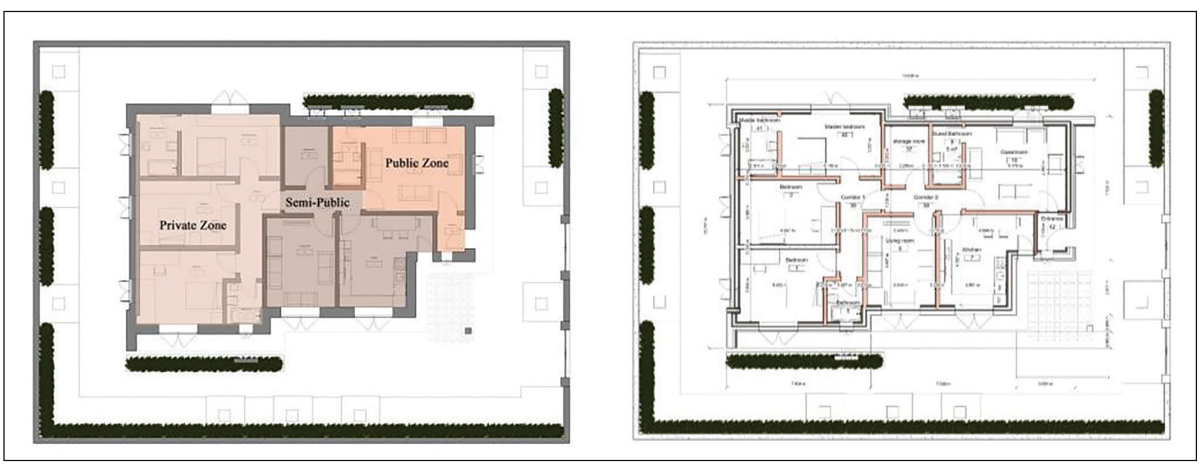


Fig. 8. The articulation concept in the optimised building is divided into three parts as shown in the architectural plans for the ground floor in the two images

1. The kitchen: in our proposed design, it is situated in the south-facing elevation, to maintain good solar gain in the winter as the kitchen is classified as a common circulation zone and its occupancy hour rate is high, so it requires more heating.

2. The living room: it is an area with many users which is used throughout the day and should face the southern direction. As a result, our proposed design is situated in the south-facing elevation, to maintain good solar gain in the winter as it is classified as one of the most occupied zones in the layout, and it is protected from the western side by a buffer zone (bathroom). The southern side offers a unique location where the low sun can heat it during the cool winter days, while the high sun can be easily shaded off during the hot summer days.

3. The guest room.

4. Bedrooms: in our proposed design, the bedroom is situated to face the western side, to avoid overheating in occupancy hours by the eastern early morning summer sun, and to be heated by the sun on the western side at the end of the day in winter with a little sunlight entering the room because of the small window size to reduce energy consumption as western elevation loses heat more than other elevations.

5. The guest bathroom: the bathroom has a lower heating requirement because it is only used for short periods, so it is classified as a buffer zone. As a result, our proposed design is situated on the northern side to protect more occupant functions from cold winter as the north elevation has a minimum solar gain.

6. The bathroom, master bathroom: in our proposed design, it is situated on the southern side, which is warm, to act as a buffer zone, since its occupancy rate is low compared to other functions in the layout.

7. Storage: building buffer spaces or parts of the building with less important functions on the northern side.

Thermal mass

The thermal mass regulates heat storage and transfer; high thermal mass materials can store more heat compared to other materials when exposed to a heat source and release the absorbed heat content more slowly. When the heat source is removed, the thermal mass can reduce peak cooling loads and indoor air temperature swings in buildings.

According to the thermal mass concept, we used a dark floor in the southern facade to

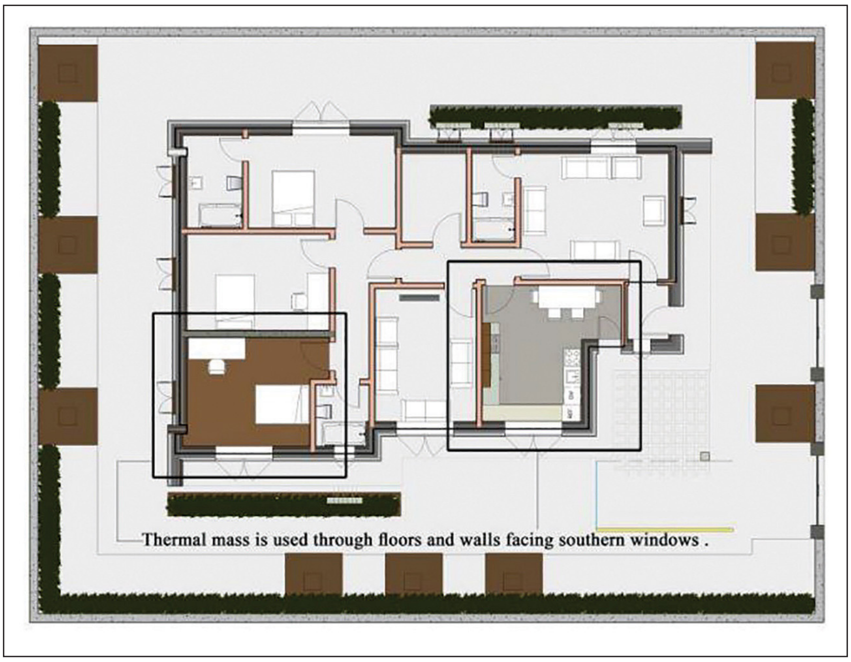


Fig. 9. The implementation of the thermal mass in the interior of the optimised building through interior floor finishing material considerations

absorb heat and radiate heat during the night; we increased the thickness of the internal wall in the southern bedroom to increase the thermal mass of this wall and to help us to heat the rooms beside it, as it is shown in Fig. 9.

Building envelope component

In contemporary architecture, the building envelope contains floors, roofs, doors, windows, and walls (external and internal), which are categorised by a multi-layered sequence of different materials and other components that allow heat transfer between the exterior environment and interior environment such as windows and doors. The challenge for the building envelope is to design it in such a way that there is an optimal balance between sufficient daylight in the building and minimal heat transfer through the envelope. The layer sequence and thickness affect the overall thermal inertia or heat storage capability. As a result, to estimate the amount of heat transferred into or out of the structure to reduce the heat loss in the winter and heat gain in the summer, the need arises to assess the thermal behaviour of a multi-layered wall, the floor, and the roof under dynamic heat transfer conditions [13, 14].

Sequence layers of external and internal walls in the base design

The construction materials that make up exterior walls, the qualities of the building element layer, and the way they are arranged all affect their thermal and physical behaviour. Huge well-insulated facades with a great heat-storing potential will reduce heat gain and loss [13]. Our proposed structural design of the building is aimed at improving conventional wall sections and experimenting with new ideas to reduce energy consumption, keeping in mind the use of materials locally produced in Jordan [17]. The base design has exterior walls and interior walls with a high U-value of 0.563 W/m·K for external walls (Table 2) and 2.5 W/m·K for internal walls (Table 3). The U-value of the exterior walls must be less than 0.57 (W/m^2·K) according to the local codes that were published by the Jordanian Ministry of Public Work and Housing, and it must be 0.40 (W/m^2·K) according to Jordan green building council; U-value of the interior walls must be less than 2 (W/m^2·K) [11]. To achieve this value, we must design a multi-layered wall with a sequence of low thermal conductivity materials to maintain a reduction in the overall U-value. As a result, we chose a wall with different materials with lower thermal conductivity than base design wall materials to reach a U-value of 0.171 (W/m^2·K).

Table 2. **The layer sequence of the external walls in the base design**

Layer type	Thermal conductivity W/m·K	Thickness (mm)
Stone	2.2	50
Reinforced concrete	2.5	100
Extruded polystyrene	0.03	50
Concrete block	1.6	100
Cement plaster	1.2	10
U-value (W/m^2·K)	0.563	

Table 3. **The layer sequence of the internal walls in the base design**

Layer type	Thermal conductivity W/m·K	Thickness (mm)
Cement plaster	1.2	30
Concrete block	1.6	100
Cement plaster	1.2	30
U-value (W/m^2·K)	2.5	

Insulation material

It is the most important layer in any building envelope component, especially in walls, as they have the most exposed surface area to the exterior environment. To maintain high inside comfort and high energy savings, the optimal choice of the insulation material depends on its thermal conductivity, thickness, and cost. Insulation thickness is directly proportional to the efficiency of the insulation and is inversely proportional to the investment cost, so the optimum insulation thickness is the thickness at which insulation efficiency and cost (capital and operational costs) are balanced [18, 19]. The base design wall configuration has one layer of insulation material: extruded polystyrene with a thickness of 50 mm and thermal conductivity of 0.029 (W/m·K). According to the simulation of the exterior walls in our proposed design and the experimental papers that studied the effect of insulation layer numbers, distribution, and thickness in the multi-layered wall, it was concluded that the optimal dynamic performances for insulation materials were obtained for all walls by placing the capacitive thermal material between two layers of thermal insulation. As a result, our experimental study proposed a wall layer sequence containing two layers of insulation materials: expanded polystyrene (EPS) and foamed polyurethane (PUR), which are widely used commercially in Jordanian constructions with savings of 34 JD/m^2 and 29.4 JD/m^2, respectively [19].

Ground floor

The heat transfer rate of floors should be 0.8 W/m^2·K to fall in line with the local codes, and the base case has a floor consisting of the above-mentioned layers in Table 4 with a total U-value of 1.877 W/m^2·K. However, the Jordan Green Building Guide proposes more efficient U-values of 0.75 W/m^2·K and 0.55 W/m^2·K, so the floor layers were improved to have a lower U-value resulting in 0.288 W/ m^2·K as detailed in Table 10 [11].

Table 4. **Configurations of the ground floor layers in the base design**

Layer name	Thermal conductivity W/m·K	Thickness (mm)
Ceramic/clay tile	0.52	30
Miscellaneous materials-aggregate	1.3	100
Concrete	1.7	320
U-value (W/m^2·K)	1.877	

Roof

The installation of a highly reflecting substance is the most typical remedy for roof heat gain. Then, it is typically bright or white in colour that produces a highly reflecting surface, limiting the radiation from the sun, keeping the area cooler, and helping to reduce energy use in the summer [11]. According to the codes that were published by the Jordanian Ministry of Public Works and housing it is preferred to have a U-value for roofs less than 0.55 W/m^2·K and 0.40 W/m^2·K to comply with the green building council guide [11], the enhanced design improved the performance of the roof according to Table 11. The detailed layers are clarified there.

Windows and glazing

Window-to-wall ratio (WWR), the daylight factor, room dimensions, window size, orientation, glazing and position. Windows have the lowest insulation value of all exterior building components. However, windows can also achieve significant solar gains, so with appropriate positioning and orientation, passive solar gains from windows can reduce heat losses. The base design window glass layer configuration is detailed below in Table 5; the configuration of glass layers is detailed in Table 6, and the configuration of window frames is detailed below in Table 7. The glazing layers were enhanced as detailed in Tables 1 and 13.

When planning transparent building elements, (g), the insulation value (U) should be as low and the passive solar gains in terms of energy transmittance value (g) as high as possible. In terms of heat gain, the highest window percentage is in the south, after the eastern and western sides, although large windows increase sunlight while minimising the need for lighting systems [24, 13]. Placing window system on the northern orientation offers the highest advantage for total energy savings, followed by the southern, western, and eastern orientation.

North-facing windows: locating window openings in the north elevation causes heat losses rather than heat gain from the sun because heat gain is too little to be considered; also, air penetration on this side is increased due to the winter winds that usually blow from the north and thus cause heat losses [13].

East- and west-facing windows: although they are less sunny in the winter than the southern façade, it is still feasible to gain some sun from the openings facing east and west. It is quite challenging to cover these openings, and we risk overheating because the summer sun rises horizontally in the morning and afternoon [13].

South-facing windows: southern windows can almost entirely rely on solar energy coming from low tilt angle in winter; while in summer, they can easily been avoided by the canopy [13].

Table 5. **The base design window glass layer configuration**

Window element	Description of the used element
Window type	Casement windows are the most energy-efficient style that we implemented in our proposed design, double glazing is also recommended in building designs in Amman. Compared to single-glazed windows, they can lead to a 25% decrease in the energy used for heating and cooling [11].
Window glass	Without reducing the amount of light, antireflective glass minimises the quantity of infrared and ultraviolet light that passes through glass. Low-E windowpanes contain a translucent, tiny film that reflects heat [11].
In-between glass material	The space between glazing panes in windows has an impact on their thermal behaviour. By employing argon gas instead of air between the glass panes of a single double-glazed pane, conductivity through windows can be minimised. The transparent, inexpensive, and non-toxic argon has a lower thermal conductivity than air [11].
Window frame	Sealant and weather-stripping material used; the window frame material is an important factor that affects the amount of heat entering through convection. Improving thermal resistance of the frame can contribute to overall energy efficiency of a window. However, the low conductivity of uPVC as a material and the tight seals uPVC windows provides them with the most energy-efficient type to be used in buildings [11].
Sealant material used in the frame	We used polyurethane (PU) foam to minimise the amount of air seeping into and out of the house. Air leaks should be sealed to save energy as using a sealant material and weatherstripping is a simple and affordable way to lower heating and cooling expenses, improve the frame's lifespan, boost comfort, and create a more pleasant interior atmosphere. Caulking and installing weather stripping around doors and windows can be used to fill the gaps [11].

Table 6. **The configuration of glass layers in base design window**

Layer	Thickness (mm)
Generic blue	6
100% Air Gap	6
Generic clear	6
U-value (W/m²·K)	3.094

Table 7. **The configuration of window frames in base design**

Layer	Thermal conductivity (W/m·K)	Thickness (mm)
Aluminium	160	2
Polyvinyl chloride (pvc)	0.17	5
U-value (W/m²·K)	5.014	

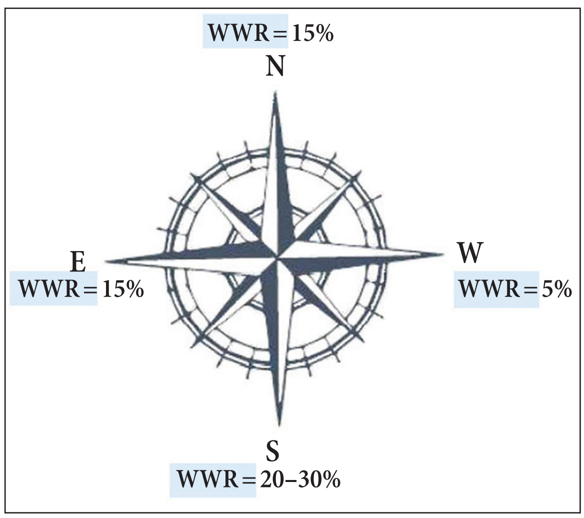


Fig. 10. Window-to-wall ratio for the four elevations

WWR (Window-to-wall ratio) WWR = Windows Area / (Total Wall Area):

When split by the area of the external walls of the space, this value represents the total area of all translucent elevation openings excluding the frames. However, in Amman, WWR should be more specific to each orientation as illustrated in Fig. 10, because each orientation differs in sun and wind exposure. Thus, the southern orientation needs a WWR with a value of 20–30%, the western orientation needs a 5% WWR, while the eastern orientation requires a 15% of WWR, and finally, the northern orientation needs a 15% of WWR [11].

RESULTS AND DISCUSSION

Building envelope elements after enhancement Layers of exterior walls

Table 8. **The developed sequence of external wall layer**

Layer	Thermal conductivity W/m·K	Thickness (mm)	Characteristics of each material
Limestone	1.5	70	The high thermal capacity of the limestone helps offset heat gain during the day and radiates it at night when the temperatures are cooler [17].
Polyurethane expanded	0.023	45	
Concrete block (Lightweight)	0.19	200	
EPS expanded polystyrene	0.035	97	Extruded polystyrene is the best type of polystyrene that may be used for insulation. It can be easily applied and is not affected by dampness, according to efficient buildings codes and materials [17, 16].
Concrete blocks/ tiles – block, with perlite, lightweight	0.33	100	
Gypsum insulating plaster	0.18	2	
U-value (W/m²·K)	0.158		

Materials were chosen according to multiple experimental studies in Jordan, their U-value, thermal conductivity, their cost, and availability in the market [17, 19].

Interior wall layers

The internal walls layer sequence of the enhanced design is detailed in Table 9. The Green Building Guide recommends boosting the efficiency of the materials used to attain 1.8 W/m²·K of thermal transmittance while the local code demands a U-value of 2 W/m²·K [11].

Table 9. **The internal wall layer sequence of the developed design**

Layer	Thermal conductivity W/m·K	Thickness (mm)
Gypsum board/Plastering	0.16	0.0127
Aerated concrete block	0.24	0.15
Gypsum board/Plastering	0.16	0.0127
U-value (W/m²·K)	1.048	

Ground Floor layers

Table 10. **The ground floor layer configurations of the developed design**

Layer	Thermal conductivity W/m·K	Thickness (mm)
Cast concrete (dense)	1.4	100
Foam – polyurethane	0.028	50
Expanded polystyrene	0.035	120
Miscellaneous materials- aggregate (sand/gravel/stone) Oven-dried	1.30	50
Cement/plaster/mortar- cement	0.72	30
Ceramic/clay tiles – clay tiles	0.85	25
U-value (W/m²·K)	0.288	

Roof layers

Table 11. **The roof layer configurations of the developed design**

Layer name	Thermal conductivity W/m·K	Thickness (mm)
Roofing materials – roof tile	0.84	40
Cement mortar	0.35	20
Loose-fill/powders – gravel	0.36	50
Foam – polyurethane	0.028	100
Bitumen, pure	0.17	50
Concrete Roofing Slab, Aerated	0.16	260
Gypsum board/Plastering	0.35	20
Total U-value (W/m²·K)	0.169	

Windows and glazing

Table 12. **The developed design window glass layer configuration**

Layer name	Thermal conductivity (W/m·K)	Thickness (mm)
Generic Low-e seal clear 6 mm	0.90	6
Argon 16 mm		16
Generic Low-e seal clear 6 mm	0.90	6
U-value (W/m²·K)	1.041	

Table 13. **The window frame configuration of the developed design**

Layer name	Thermal conductivity (W/m·K)	Thickness (mm)
Polyurethane (PU) foam	0.05	25
Polyvinylchloride (PVC)	0.16	93
U-value (W/m²·K)	0.799	

Daylight access design factors:

1. Strategic positioning of windows and envelop openings, where lighting is needed.

2. Visual comfort; excessive contrast and glare are avoided.

3. Windows should be designed to avoid direct sunlight access; also, small windows in thick walls could be efficient.

4. Shading elements: diffused light provided, and heat gain reduced.

The relationship between the quantity of daylight that is accessible outdoors due to an overcast sky and the illumination at a surface is known as the 'daylight factor' [11]. According to the following equation, window openings have an impact on how much daylight reaches a building and should be carefully planned to ensure enough daylight factor. After calculating the daylight factor for each space, Tables 14 and 15 define the window area required in each space of the optimised model.

$$D = \frac{W}{A} \cdot \frac{T*O}{(1-R^2)}, \quad (1)$$

where D = average daylight factor, W = window area in m², A = area of all surfaces of the room in m² (floor, ceiling, and walls including windows), T = glass transmittance (0.75 for clear double glazing), O = visible sky angle, in degrees, R = average reflectance of area A (0.50 for light surfaces) [11].

Table 14. **Daylight Factor**

Room type	Average daylight factor	Minimum daylight factor
Kitchen	2	0.60
Living room	1.5	0.50
Bedroom 1	1	0.30
Bedroom 2	1	0.30
Master bedroom	1	0.30
Guest room	1.5	
Corridor 1	2	0.60
Corridor 2	2	0.60

Natural ventilation

Wind direction, position and size of windows, cross ventilation, one-sided ventilation passive cooling and ventilation through ventilated cooling; the exchange between hot air and cold air through wind pressure movement – all these factors were considered and implemented in the developed design as shown in Figs 11 and 12, these strategies use both wind and temperature difference to cool by ventilation, which can release heat and thus reduce the cooling load. Natural airflow contributes to indoor climate comfort. In addition, it improves indoor air quality; however, dust infiltration should be prevented [13, 14].

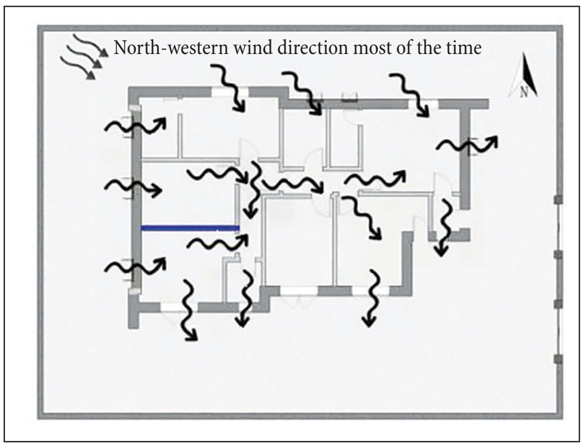


Fig. 11. Clarification of natural ventilation through the horizontal section of the building

The single-sided ventilation and cross ventilation strategies are used in the developed design through making the building orientation towards the prevailing wind direction. While the location of openings, and windows, towards the prevailing wind direction are also designed according to the passive design strategy.

The size of the inlet and outlet openings

The inlet of air should be larger than the exit to accommodate good airflow; it is recommended in

Table 15. **Daylight analysis and window area equation**

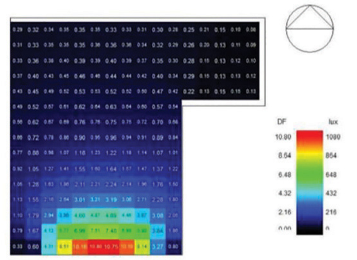
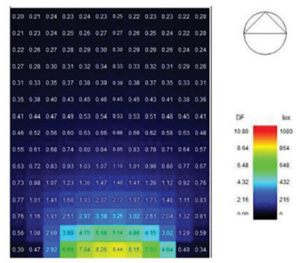
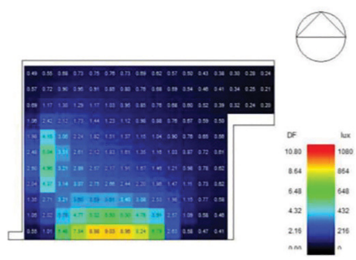
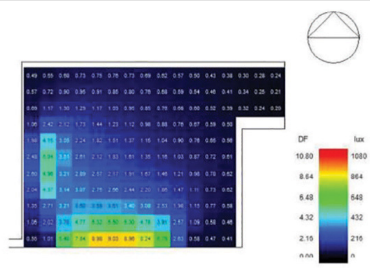
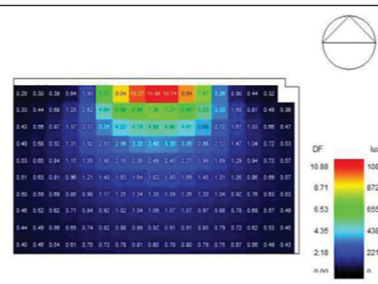
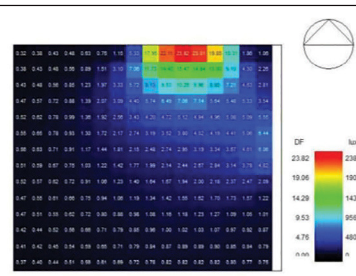
Function name	Window area equation	Daylight analysis
Kitchen	$2=\frac{W}{89.24}\,\frac{O\,0.77*66.32}{(1-0.25)}=2.63\ \text{m}^2$ (2)	
Living room	$1.5=\frac{W}{85.53}\,\frac{O\,0.77*66.32}{(1-0.25)}=1.95\ \text{m}^2$ (3)	
Bedroom 1	$1=\frac{W}{85.747}\,\frac{O\,0.77*52}{(1-0.25)}=1.6\ \text{m}^2$ (4)	
Bedroom 2	$1=\frac{W}{89.648}\,\frac{0.77*73.28}{(1-0.25)}=1.192\ \text{m}^2$ (5)	
Master bedroom	$1=\frac{W}{86.12}\,\frac{0.77*90}{(1-0.25)}=0.93\ \text{m}^2$ (6)	
Guest room	$1.5=\frac{W}{105.062}\,\frac{0.77*90}{(1-0.25)}=1.7\ \text{m}^2$ (7)	

Fig. 12. Clarification of natural ventilation through a vertical section of the building

the architectural plan to have the door and window opposite each other.

Landscape strategies

The studied area has a moderate climate has a moderate climate that enhances the heating effects of the sun in winter and the benefits of shade in summer. Therefore, it is crucial to shield buildings from winter winds and attract summer breezes in their direction. Applying trees as building shading devices is an efficient passive method of solar control. In the shaded area, the irradiative and thermal loads are significantly lower compared to the non-shaded ones. Through evaporative cooling, trees can lower air temperature around the shaded walls. Reducing emissions due to the energy savings and the aesthetic influence of trees on urban landscapes are additional advantages of using trees as shading devices [21]. On the northern façade, green trees with bushes should be planted to shield it from brisk winter winds as shown in Fig. 16. While on the southern front, low plants or trees should be used, and on the eastern and western sides, tall evergreen trees should be planted, as shown in Figs 14 and 15, to block the sun since solar angles are lower at these sides and allowing natural ventilation. Moreover, high trees that have a canopy effect can protect elevation from the high south sun angle, deciduous trees, losing the leaves before the winter, do not block the winter sun and prevent the summer sun from reaching a building, as shown in Fig. 13 [13, 14]. On the southern elevation, a medium-sized deciduous tree can reduce irradiance by 80% (with leaves on it) and 40% (leafless). Moreover, the best two places to plant a tree are near a building in order to reduce cooling costs are in front of west-facing windows and walls and in front of the east facade by providing shade for these facades in the morning and afternoon. Also, in order to reduce energy use in winter, the most valuable way is to consider the use of trees as windbreakers to the north and

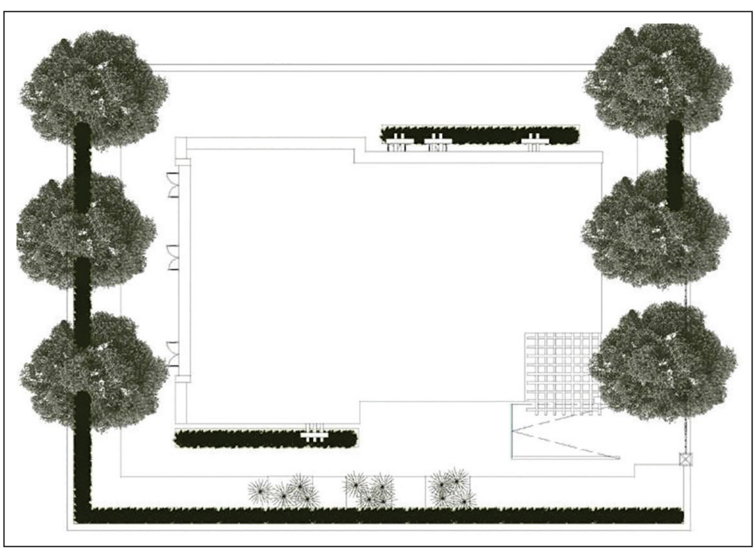


Fig. 13. Site plan of the optimised building with landscape strategies

Fig. 14. The western elevation

Fig. 15. The eastern elevation

Fig. 16. The northern elevation

northwest of a building to protect it from the cold north winter wind [21].

The implementation of shading devices

Shading devices such as overhang, shutter windows and wing and free-standing walls were also used in the design of the house; it is shown through four elevations and multiple views. Figs 17 and 18 clarify the technique of using free-standing walls in the southern orientation and the overhang, while Fig. 19 shows the implementation of the wing wall and shutter windows in the eastern orientation and free-standing walls in the northern orientation. Finally, the west orientation as shown in Fig. 20 it is enhanced using shutter windows and landscape strategies as explained in the previous section.

Artificial lighting analysis

In Jordanian apartment blocks, efficient lighting fixtures must be installed in place of outdated ones. Additionally, 90% of the energy used by conventional light bulbs is converted into heat,

Fig. 17. The south-eastern view

Fig. 18. The southern view

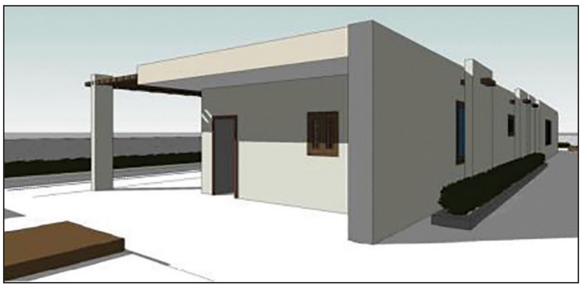


Fig. 19. The east-northern view

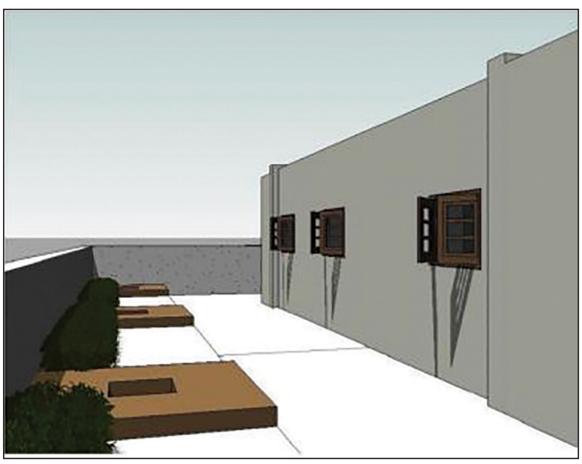


Fig. 20. The western view

which raises summertime temperatures. As a result, energy-efficient lighting systems, such as CFLs and LEDs, which are best for reducing energy consumption, should be used [11]. In the developed design the lighting intensity was determined for each space according to its function, as detailed in Table 16.

Table 16. **The light level and lighting power density for each room type**

Room type	Light level (Lux)	Lighting power density (W/m²)
Kitchen	300	12.9
Living room	100	7
Bedroom 1	200	4
Bedroom 2	200	4
Master bedroom	200	4
Master bathroom	100	10.5
Bathroom	100	10.5
Storage room	50	6
Guest room		9
Guest bathroom	100	10.5
Corridor 1	50	7
Corridor 2	50	7
Entrance	50	6

Heating and cooling load results for the baseline and developed models

The passive house analysed, with 186 m^2 usable floor area, was designed to minimise the energy consumption and the high quality of the living environment. This dwelling meets the passive house standards and benefits from its excellent building fabric design. The residents of the house were satisfied with the comfortable indoor environment achieved during winter and summer. After retrofits, the consequent reduction in yearly heating load changed from 10 kWh/m^2 to 5.6 kWh/m^2, the annual cooling load from 3.12 kWh/m^2 to 2.29 kWh/m^2, and the annual lighting load from 36.7 kWh/m^2 to 10.7 kWh/m^2 as detailed in Tables 17 and 18. Therefore, the total heating load can be minimised by nearly 44% and the total lighting load by nearly 70.8% by simply adding the insulation layer to the walls and roofs, changing the window types and placement, improving the construction layers, changing the orientation of the building, changing the interior design of the building by adding the thermal mass concept, improving the lighting system, etc. The details of monthly variations of the heating, cooling load and lighting loads before and after the improvements are shown in Figs 21 and 22, respectively, and the reduction in the lighting, heating, and cooling loads is clearly seen in each figure. As expected, with higher values of energy needed for heating and much lower values for cooling in our location, lighting energy needs vary throughout the specified year.

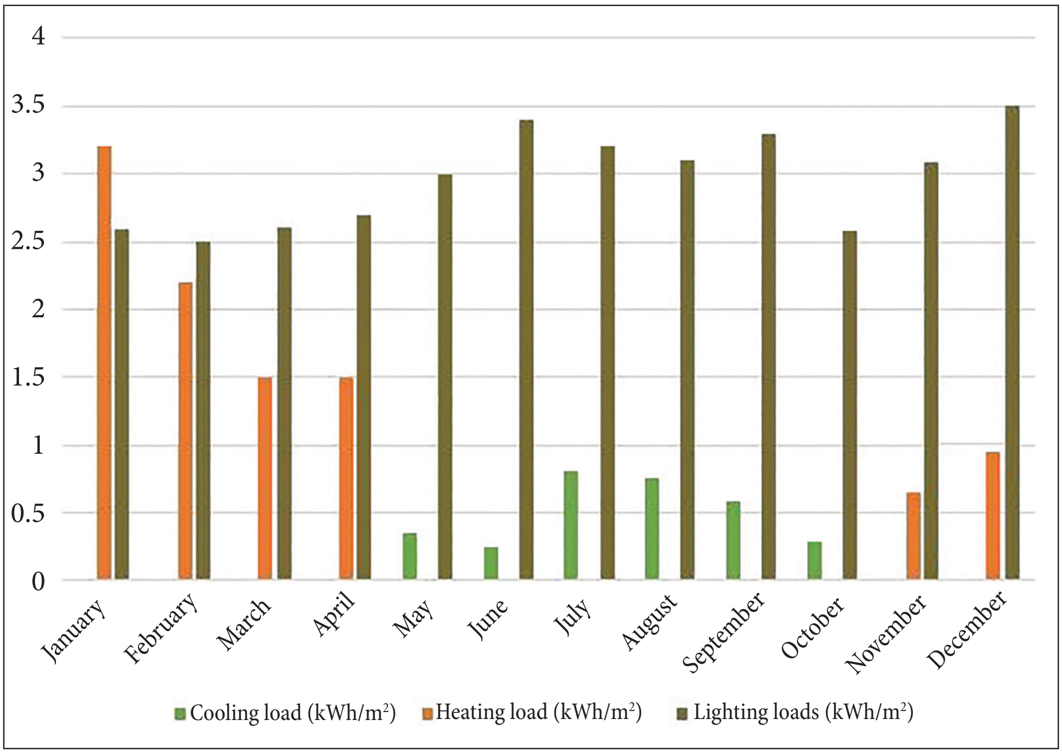


Fig. 21. Energy consumption through the year for the baseline model (cooling load, heating load, lighting load), kWh/m²/month

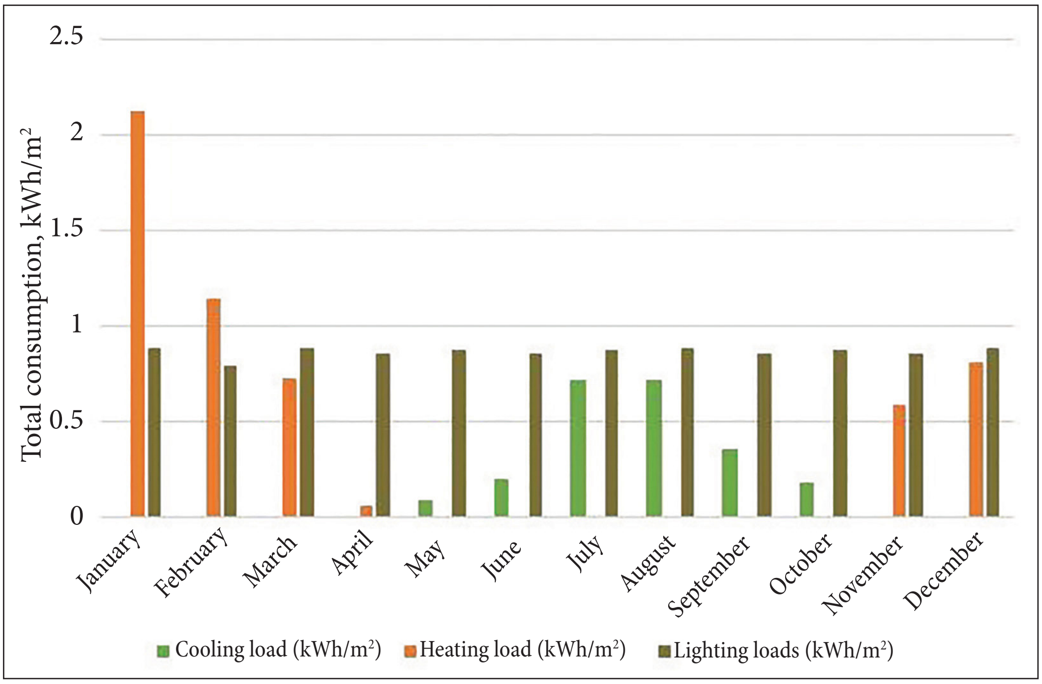


Fig. 22. Energy consumption for the developed model through the year (cooling load, heating load, lighting load), kWh/m²/month

Table 17. **Energy consumption for the baseline model (lighting, cooling, heating), kWh/year**

Electrical loads	The electrical consumption (kWh/year) for the baseline model	The electrical consumption (kWh/year) for the developed model
Heating loads	1859.1	1011.5
Cooling loads	561.7	412.3
Lighting loads	6613.6	1926

Table 18. **Energy consumption for the developed model (lighting, cooling, heating) in kWh/ m²/year**

Electrical loads	The electrical consumption (kWh/m²/year) for the baseline model	The electrical consumption (kWh/m²/year) for the developed model
Heating loads	10	5.6
Cooling loads	3.12	2.29
Lighting loads	36.7	10.7

The temperature and heat loss in the base and passive design, 9°C is the setpoint temperature of the basic design model in the winter but we have enhanced the operating temperature in our passive design to reach 18°C which improved the thermal comfort inside the house. Moreover, we have made huge improvements to overcome the heat loss problems, Table 19 shows the losses through the building before and after the retrofits. It is noticed that the design still has some losses through our developed design due to various reasons, such as not all the variables were considered in our retrofit strategies and the simulation process; such as the analysis of the thermal bridges, isolating the door material, changing the slope of the roof, the design is clear active to the south.

Table 19. **Losses through the building before and after**

Loss types	Baseline model (kW)	Retrofitted model (kW)
Glazing losses	–2.08	–0.079
Walls	–1.21	–0.129
Roof	–1.56	–0.13
External infiltration	–10.61	–0.78
Zone sensible heating	15.73	3.83
External ventilation	–0.41	–3.25

Solar gain results

Solar gains through the building structure are among the sources of natural energy gains. To manage the amount of provided energy needed by the building, it is crucial to regulate the entry of natural energy into facilities while taking climatic circumstances into account. Solar heat gain can raise the room temperature and lead to hyperthermia in hot climes. Therefore, it should be managed by design techniques like natural ventilation and shading. On the other hand, in cold areas, passive heating and other natural heat sources can cut down on the number of thermal loads. Solar access and air velocity around buildings are influenced by the site's terrain, direction, and setbacks between structures, which have an impact

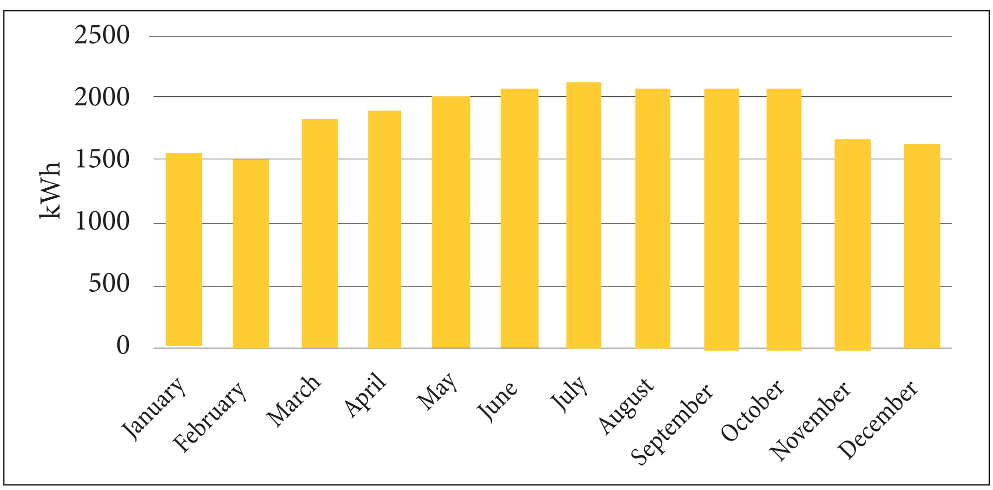


Fig. 23. Monthly average solar gain in the basic design model, kWh

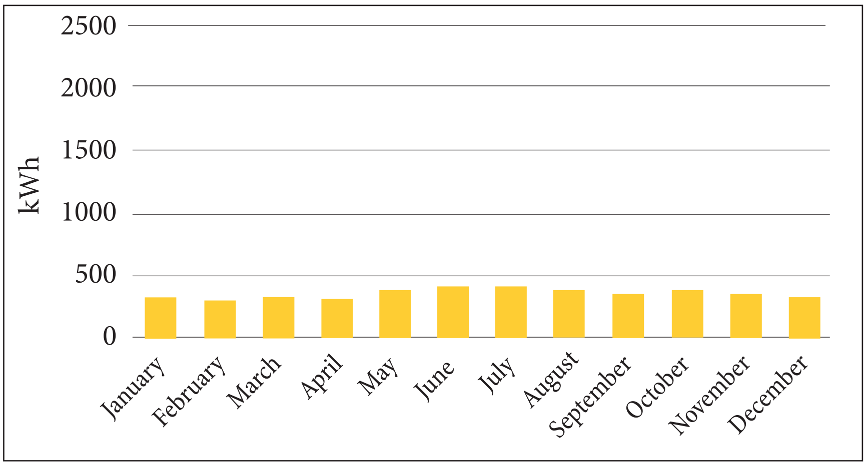


Fig. 24. Monthly average solar gain in the optimised design, kWh

on heating and cooling demands of the buildings. As direct sunlight increases cooling demand and promotes excessive heat in buildings during the summer, it is crucial to keep it out of those spaces. Although it is an available source of heat in the winter, it can raise the temperature in the building and lower the heating demands. It is believed that the sun in the east and west is lower, stronger, and harder to regulate. It is simpler to block southern solar access in summer by employing a canopy because the sun is positioned higher in the sky and vertically. By using a shade mechanism and lowering the interior temperature during the summer months as shown in Figs 23 and 24, the solar gain was lowered in the passive design [10]. Figs 25 and 26 illustrate the incident angle for both designs in the summer and winter as it was observed that the southern shading devices block the summer sun and the winter sun reaches the house at a lower angle than the summer sun, which decreases the interior temperature during the summer seasons and consequently reduces

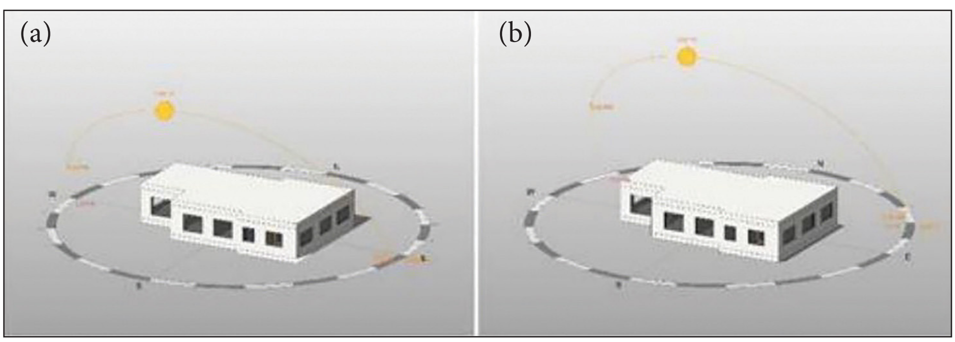


Fig. 25. Solar profile for the basic design model in (a) winter and (b) summer

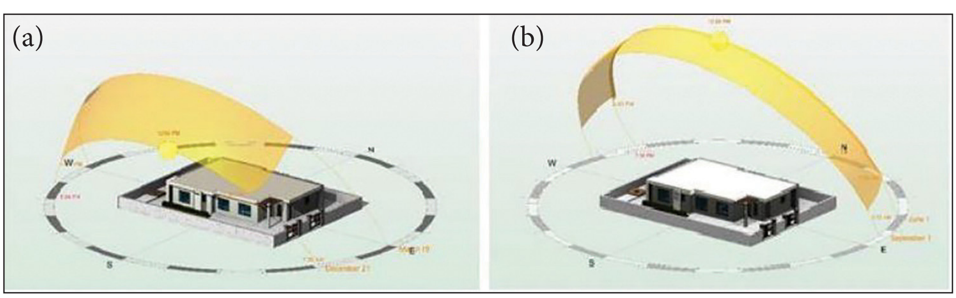


Fig. 26. Solar profile for the optimised design in (a) winter and (b) summer

the cooling demand and provides a heating boost during the winter seasons that reduces the heating loads.

CONCLUSIONS

This paper presents a simulation analysis to enhance the energy behaviour of a home in Amman, Jordan, using renovating approaches. Using passive energy-saving techniques, this house was modified with the intention of lowering annual energy usage. Multiple architectural design methods were used to minimise energy consumption in the design, through which architecture has the main influence on the occupants whose energy affects them all the time either by cooling in the summer or heating in the winter. We started from the preliminary design to consider energy and human thermal comfort; orientation, building aspect ratio, building form, human circulation in the house, location of the house functions, where they mostly fit in terms of reducing energy consumption by achieving the concept of articulation to control heating and cooling zones and avoid losses through different functions in the house. The windows were studied hard starting from their size to position and location in the wall to their percentage of the floor area to their function of natural ventilation and solar gain. Moreover, window component such as frames and sealant materials were taken into consideration and calculation. Moreover, the floor, the roof, and wall layers were enhanced using new layers of materials and adding insulation material to estimate the least energy consumption to comply with the passive house strategies, and, finally, landscaping design strategies were implemented strictly with shading elements achieving the same concept. The baseline model consumes 48.62 kWh/m^2/year of energy for heating, cooling, and lighting before implementing the optimised model techniques; in winter, the average temperature in the house was 9°C. After renovation, the actual data shows the electrical consumption was reduced to 18 kWh/m^2/year. The indoor temperature in winter reached 18°C, which is higher than the temperature of the basic design. The solar gain was reduced in the passive design due to using shading devices and minimising the interior temperature during the summer season.

Future studies should focus on improving the behaviour of additional elements in terms of reducing heating and cooling loads in the building envelope such as thermal bridges and roofing slopes; also, an integration of active systems with the passive system should be rendered more realistic with similar studies in the same climate zone and investigation area [27, 29]. Also, a good consideration of the thermal behaviour and the comfort of the human being must be studied and analysed to these modifications [28]. To finalize, this research suggests very intensive ways of designing a passive house and recommends all architects to design buildings carefully by giving priorities to green and sustainable design strategies before many other considerations as buildings contribute to a significant value in the global problem we are now facing, the climate change crisis. Immediate actions must be taken against it and about the ways we should adapt to it in many fields.

Received 30 May 2022
Accepted 14 November 2022

References

1. Shamout E. Your_Guide_To_Building_Envelope_Retrofits_English.Pdf. 2020. [online] Google Docs. Available at: <https://drive.google.com/file/d/1iUk8Dd59jIt27ucudGbk7mXgth2yKrxk/view. [Accessed 10 May 2020].
2. "Home." Department of Statistics. http://dosweb.dos.gov.jo/product- category/Jordan-in-figuers_yearbook/. [Accessed 11 May 2020].
3. Hikmat A., Hashlamun R. Envelope retrofitting strategies for public school buildings in Jordan. *Journal of Building Engineering*. 2019. Vol. 25. ID. 100819. doi: 10.1016/j.jobe.2019.100819
4. International Passive House Association. The Passive House Brochure. Available at: https://passivehouse-international.org/index.php?page_id=70. [Accessed May 11, 2020].
5. DesignBuilder Documentation, DesignBuilder User Manual. Version 2.1; DesignBuilder Software Limited: Gloucestershire, UK, 2009.
6. Shaeri J., Habibi A., Yaghoubi M., Chokhachian A. The Optimum Window-to-Wall Ratio in Office Buildings for Hot-Humid, Hot-Dry, and Cold

Climates in Iran. *Environments.* 2019. Vol. 6(4). 45. doi: 10.3390/environments6040045

7. Liang X., Wang Y., Royapoor M., Wu Q., Roskilly T. Comparison of building performance between Conventional House and Passive House in the UK. *Energy Procedia*. 2017. Vol. 42. P. 1823–1828. doi: 10.1016/j.egypro.2017.12.570
8. Yu Media Group. Amman, Jordan – Detailed Climate Information and Monthly Weather Forecast. Weather Atlas. https://www.weather-atlas.com/en/jordan/amman-climate. [Accessed May 14, 2020].
9. ASHRAE Standard 62-2001, Ventilation for Acceptable Indoor Air Quality. 2001.
10. Developing an Energy Benchmark for Residential Apartments in Amman. Jordan GBC. http://jordangbc.org/blog/project/2134/. [Accessed May 16, 2020].
11. Nazer H. Developing an Energy Benchmark for Residential Apartments in Amman. Amman, Jordan: Jordan Green Building Council, 2019. 128 p.
12. Passive Housing Design in a Tropical Climate. United Kingdom: Chayakorn Kunajitpimol. 2009. 125 p.
13. Yüksek I., Karadayi T., Energy-Efficient Building Design in the Context of Building Life Cycle. [ebook] IntechOpen, 2017. 33 p. Available at: doi: 10.5772/66670 [Accessed 1 April 2020].
14. Florentine V., Yeretzian A. Energy Efficient Building Guideline for MENA Region. Ebook. Cairo-Rabad Kandil:: The European Union. http://www.med-enec.eu. 2013.
15. Vrachliotis G. Articulating Space Through Architectural Diagrams. Ebook. Zurich, Switzerland: Faculty of Architecture, ETH Zurich. 2005.
16. Alshorman A. A., Al bkoor Alrawashdeh K., Alshorman M., Talat N. T. Validation of Jordanian Green Building Based on LEED Standard for Energy Efficiency Methodology. *Jordan Journal of Mechanical & Industrial Engineering*. 2018. Vol. 12. No. 1. P. 51–58. http://jjmie.hu.edu.jo/vol12-1/JJMIE-2018-12-1.pdf
17. Khasawneh J. AREE – Aqaba Residence Energy Efficiency. Ebook. Amman: The Center for the Study of the Built Environment. 2011.
18. Hamdan M., Malek M. K. Optimization of insulation thickness for building's external wall in Jordan. *International Conference on Water, Energy, and Environment*. American University of Sharjah (AUS). UAE. 2017.
19. Batiha M. A., Marachli A. A., Rawadieh S. E., Altarawneh I. S., Al- Makhadmeh L. A., Batiha M. M. A study on optimum insulation thickness of cold storage walls in all climate zones of Jordan. *Case Studies in Thermal Engineering*. 2019. Vol. 15. ID. 100538. doi: 10.1016/j.csite.2019.100538
20. Nematchoua M. K. At Application of phase change materials, thermal insulation, and external shading for thermal comfort improvement and cooling energy demand reduction in an office building under different coastal tropical climates. *Solar Energy*. 2020. Vol. 207. P. 458–470. doi: 10.1016/j.solener.2020.06.110.
21. Ogbeba J. E., Hoskara E. The evaluation of single-family detached housing units in terms of integrated photovoltaic shading devices: The case of Northern Cyprus. *Sustainability.* 2019. Vol. 11. No. 3. ID 593. doi: 10.3390/su11030593.
22. Alyami M., Omer S. Building energy performance simulation: a case study of modeling an existing residential building in Saudi Arabia. *Environmental Research: Infrastructure and Sustainability*. 2021. Vol. 1. No. 3. ID 035001. doi: 10.1088/2634-4505/ac241e.
23. Ascione F., Bianco N., Iovane T., Mastellone M., Mauro G. M. Is it fundamental to model the inter-building effect for reliable building energy simulations? Interaction with shading systems. *Building and Environment*. 2020. Vol. 183. ID 107161. doi: 10.1016/j.buildenv.2020.107161.
24. Samuelson H. W., Reinhart C. F. Modelling an existing building in DesignBuilder/EnergyPlus: custom versus default inputs. *Building Simulation*. Eleventh International IBPSA Conference, Glasgow, Scotland, July 27–30. P. 1252–1259. 2009. https://www.researchgate.net/publication/228453444
25. Ababsa M. *Atlas of Jordan: History, Territories and Society*. Presses de l'Ifpo, Institut français du Proche-Orient. 2013.
26. Jordanian National Building Council. *Thermal Insulation Code* (2nd edition). 2009.

27. Albatayneh A. Rooftop photovoltaic system as a shading device for uninsulated buildings. *Energy Reports*. 2022. Vol. 8. P. 4223–4232. DOI: 10.1016/j.egyr.2022.03.082.

28. Albatayneh A. Reducing the operating energy of buildings in arid climates through an adaptive approach. *Sustainability.* 2022. Vol. 14. No. 20. ID 13504. doi: 10.3390/su142013504.

29. Albatayneh A., Albadaineh R., Juaidi A., Abdallah R., Zabalo A., Manzano-Agugliaro F. "Enhancing the Energy Efficiency of Buildings by Shading with PV Panels in Semi-Arid Climate Zone", *Sustainability*. Vol. 14. No. 24. P. 17040, Dec. 2022. doi: 10.3390/su142417040.

Renad Wael Albadaineh

ENERGIŠKAI PASYVAUS GYVENAMOJO PASTATO PROJEKTAS AMANE, JORDANIJOJE