Net-zero Individual Housing: Investigating Passive Retrofitting Scenario in Warm Mediterranean Climate

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Abstract
The residential sector is responsible for 40% of the energy consumed for space cooling in warm Mediterranean climates. This is a result of construction materials’ poor thermal performance and long hot summers. Therefore, the aim of this research is to study the impact of solar radiation on the external envelope and the thermal performance of a stone house towards high outdoor temperatures to minimize energy consumption for summer indoor cooling during the summer of 2021 to meet a net zero energy target in a warm coastal area of Lebanon. This is done by software simulation and internal dry bulb temperature monitoring. The passive retrofitting strategies analysed showed that energy consumption could be reduced by 56%. This incorporates installing a photovoltaic system. Figures will show that 25m² of solar panels can mitigate the summer’s cooling energy consumption.

Highlights
- Passive retrofitting strategies for energy reduction.
- Enhancing building’s thermal performance.
- Decrease energy consumption for summer cooling.
- Using solar radiation to mitigate energy consumption.

Introduction
The worldwide residential sector consumes around 40% of the global energy and is responsible for 33% of the global CO2 emissions (Ürge-Vorsatz et al., 2015). High energy consumption in warm and hot climates is noticeable due to the need for a high portion of indoor space conditioning for maintaining occupant comfort (Friess & Rakshshan, 2017). Hence, each building’s energy consumption depends on the climate factor, the thermal properties of its envelope, and occupant behavior (Gyamfi et al., 2013). In warm climates, indoor space cooling relies on electricity as a source of energy (Gyamfi et al., 2013). The electricity sector in Lebanon cannot meet the market need. Besides, no oil and gas resources are found in Lebanon, and all fuel is imported. Therefore, private generators provide the needed electricity across Lebanon (Ahmad et al., 2021). Furthermore, it is expected that by the year 2100, the cooling demand will increase by 72% globally (Isaac & van Vuuren, 2009). Hence, the need for decreasing energy demand is projected to minimize the impact on the environment. Jounieh, Lebanon is located in the coastal part of the country, in the eastern part of the Mediterranean Sea, classified as the warm and humid zone, having cool and short winters, hot, humid, and long summers with no precipitation (UNDP, 2005). This research recorded and investigated the temperature behavior of stone houses during the summer and fall of 2021, (where all the houses constructed during the early years of the 20th century were made of limestone). Limiting the focus on minimizing the energy spent on summer cooling indoor spaces in the residential sector. This research monitors the internal temperature of a house for a period from August 2021 to September 2021. The average outdoor temperature is 29 °C, a minimum of 24 °C, and a maximum of 33 °C as recorded during the study period. The average daily solar radiation recorded is 576 Wh/m². These temperature and solar radiation data were gathered from a Davis weather station located on a nearby building’s roof. Similarly, data on daily electricity consumption for indoor cooling is also recorded.

Several studies have tackled the issue of reducing energy consumption by minimizing the demand for cooling in warm and hot climates (Visser et al., 2013), (Bretz et al., 1998), and (Prado et al., 2013). Their research outlined the reliance on passive strategies switching to being independent of fossil fuels. These strategies are natural ventilation, passive cooling, and reducing heat gain from the roof. Retrofitting has been addressed to improve indoor comfort conditions and reduce energy demand and consumption. (Blázquez et al., 2019) proposed retrofitting strategies for improving ventilation and adding insulation layers on 218 housing units. (Suárez et al., 2015) applied to retrofit strategies for a 68-apartment unit in a residential building in Cordoba, Spain. Results show that this reduced 38% of the total energy demand. (Suárez et al., 2015) highlighted a significant envelope improvement as increasing insulation and night ventilation. This led to a reduction of 27% of energy for indoor cooling. (Panayi, 2004) Investigated the impacts of different passive strategies for retrofitting on cooling energy consumption as insulation, glazing, thermal mass, and orientation of a house in
Nicosia, Cyprus. The analysis was conducted through simulation software. Results showed that the most effective measure is double glazing, 25 mm of wall insulation, thermal mass, and roof insulation. (Florides et al., 2000) studied a house in Cyprus analysing its cooling load throughout the year. Results showed that roof insulation reduces cooling demand by up to 57%.

**Methods**

To begin with the fieldwork, this research is carried out on a residential house located in Jounieh area (33.9843° N, 35.6344° E), 20 km northeast Beirut, 60 m above sea level (Figure 1), monitoring its internal temperature for a period from August 2021 till September 2021 (summer of 2021). It is a two floors residential house having two different external envelopes: limestone 30 cm for the external and internal walls and concrete masonry unit (CMU) 10 cm for the rooms that have been added lately. The roof is made of reinforced concrete 15 cm. The slab between the ground floor and the first floor is a steel structure slab covered with ceramic tiles. All the internal walls are plastered and painted, and the windows are single-glazed with a wooden frame.

![Figure 1: Picture showing the studied house. Source: Authors.](image1)

The house has two balconies, one towards the north (14 sq. m), while the other one is towards the southeast and closed with single-glazed curtain glass. The closed balcony is 25 sq. m and its roof is made of steel structure covered with red roof tiles. The ground floor sums up to 113 sq. m, while the first floor is 37 sq. m. The living area and the dining area on the ground floor have a double height of 6 m. The bedrooms on the ground floor are covered with corrugated sheet shading elements to use the space underneath them as a storage area.

The observation was divided into two categories. The first one (category A) is the rooms that had the air conditioning (AC) on as long as the electricity was available during the period of the study. While the second category (B) contains the rooms that do not have an air conditioning (AC). The AC in category A work according to the availability of electricity. This is due to Lebanon suffering from daily power shortages. Affected by the high demand for electricity and the inefficiency of power plants. According to (Fardoun et al. 2012, p.317), There is a lack of electricity to meet market demands, where the demand increases while the supply decreases.

![Figure 2: Ground Floor and First Floor Plans of the Studied House. Source: Authors through Revit Autodesk 2020](image2)

The current situation depends on the private sector supplying the required energy through diesel generator. The energy used for the residential sector shows that the main consumption is on summer cooling demand (MOEW/GEF/UNDP, 2015, p. 19).

Recorded temperature show that peak temperature occurs after mid-day hottest peak when the solar radiation is directly hitting the room and external walls. Also, the
temperature within the most exposed rooms to the sun is constantly higher than in the other rooms. This was shown during the observed period where the inside temperature is above the comfort band. This is in clear contrast with the recorded rooms that were least exposed to solar radiation where it was within the comfort band.

In addition, the monitoring instruments consist of a Davis weather station which was installed on a nearby building’s roof to record the outdoor air temperature and solar radiation at hourly intervals in °C. Also, Tiny Tag data loggers were installed in each room of the house recording the dry bulb temperature at the hour in °C. All of these values are used in the analysis to compare internal and external temperatures. Moreover, a single-phase energy meter was installed to record the air-conditioning consumption in terms of electricity in Wh.

Furthermore, the Jounieh house was modelled by using Revit Autodesk 2020 as thermal simulation software (Figure 3). Results were compared to the recorded temperature data. Besides, the weather condition and the building envelope’s thermal properties (U-values) are the parameters taken into consideration. Subsequently, the model was constructed and simulated by retrofitting the house in terms of enhancing the external envelope’s thermal properties to minimize cooling demand. Insight 360 (Autodesk) and Green Building Studio (GBS) are energy simulation software that allows designing, analysing, predicting, and evaluating energy consumed in models in a specific location, orientation, and climatic conditions (Fazi et al., 2015) and (Autodesk Knowledge Network 2020). In order to simulate the models and analyse them, each material’s thermal properties were identified.

Figure 3: Isometric Section showing the inner space of the House. Source: Authors through Revit Autodesk 2020.

This study tackles net zero-energy building through retrofits to reduce energy loads consumed on summer indoor cooling through reducing solar radiation from hitting the external envelope of the house and increasing material thermal resistance. Reaching production of enough renewable energy through photovoltaic panels to meet its own energy consumption, thereby reducing the use of non-renewable energy in the building sector.

**Results**

The monitoring period showed that each room performed differently with significant day and night temperature differences, and with exposure to solar radiation (Figure 4). During the day, bedroom #4 (1st floor) had the highest indoor dry bulb temperature and recorded the hottest peak between the other rooms, while bedroom #2 (ground floor) recorded the warmest score and maintained the coolest (Figure 4).

Initially, during days 239 and 240 on the 27th and 28th of August 2021 (Figure 4), the highest outdoor temperature trend was recorded during daytime 32.8°C. This is reflected in the inner temperature of bedroom #4 where it recorded a peak temperature of 38.3°C. As soon as the air-condition (A/C) was turned on, the internal temperature of the room dropped to reach 27.8°C (day 239). Once the A/C was turned on (day 240), the room kept cooler than the previous day and reached a maximum of 34.9°C which is lower than day 239.

Observation showed that during day 239, the A/C was turned on for 12 hours simultaneously. While, during day 240, the A/C was turned on for 17 hours simultaneously. This reflects the indoor temperature of the room that differs between these two days while having almost the same outdoor temperature and solar radiation. According to figure 4, the A/Cs consumed 50 kWh at day 239 while on day 240 it consumed 56 kWh. Although, having an A/C running more than half of the day, the temperature of bedroom #4 did not drop below the outdoor temperature.

The observation of the closed balcony showed that during noon, the internal temperature start increasing. This is due to the orientation of the room which is towards the southeast (Figure 4). This was evident during the study period, where temperature start increasing until it reaches its peak during the day. This is where the A/C was turned on and started decreasing the internal temperature. Accordingly, with a minimum of 12 hours of A/C running, also the closed balcony did not reach a temperature below the outdoor temperature during the day.

Internal peaks and fluctuation happened at various times during the day; this occurred due to the electricity blackout. As shown in figure 4, when the electricity is cut off, the internal temperature of the closed balcony increases rapidly. Bedroom #1 (below bedroom #4 on the ground floor) has the coolest temperature compared to the rooms that use an A/C in the house.

Observation shows that during day and night, this room had its inner temperature below the outdoor temperature. The daily temperature peaks sharply afternoon. This is due to the orientation of the bedroom towards the west. When the internal temperature starts rising, the A/C was turned on to decrease the room temperature. Accordingly, the temperature drops until the A/C was shot-off. Internal peaks and valleys happened at various times; as a general trend, they occurred due to electricity blackout with a malfunction of the A/C. So far, these three rooms showed that the direct exposure to the solar radiation due to the orientation highly affect the indoor temperature. In order to assess the impact of the external envelope on the internal temperature, a comparison of bedroom #2 which is situated on the ground floor, where the solar radiation doesn’t hit the room due to the shading platform on its...
Figure 4: Comparison between indoor and outdoor temperature. Source: Author
elevation, and bedroom #3 which is situated on the first floor where its roof is totally exposed to the solar radiation during the day.

Days 239 and 240 recorded the highest temperature during the studied period compared to day 243 which has the lowest temperature recordings and lowest solar radiation at that week. Figure 5 shows that bedroom #2 has almost a daily repetitive fluctuation of 1.5°C temperature difference between day and night. While bedroom #3 has a difference of 5.7°C between day and night. Subsequently, when the outdoor temperature reaches its lowest recording which is 24.5°C, the internal temperature of bedroom #2 drops to reach 28.1°C. Yet bedroom #3 recorded 30°C. However, when the outdoor temperature reaches its daily peak which is 32.8°C, the internal temperature of bedroom #2 records 29.6°C while bedroom #3 reaches 35.7°C. It is noticeable that the internal temperature of bedroom #2 does not exceed the external temperature where it fluctuates at a constant temperature. Whereas, the lowest temperature recorded in bedroom #3 is higher than the outdoor temperature.

Besides, the dining room temperature monitoring showed that internal temperature is affected by the solar radiation hitting its roof. The gap between the lowest and the highest internal temperature is around 2°C difference. Observation shows that the peak internal temperature occurred in the afternoon, this is due to the external envelope facing the west orientation and exposure to the sun radiation. This can be shown during each day of the studied period. Throughout days 238 and 239 (Figure 5), the temperature at 12:00 pm recorded 29.9°C. The internal temperature starts increasing until reaching an indoor temperature of 31.9°C as a peak dry-bulb temperature at 7:00 pm. this is when the sunset during the summer season. After this action, a decrease in internal temperature occurred until reaching a temperature of 30°C.

Discussion

So far, the monitoring of the house showed the impact of the exposure to solar radiation and the actual construction materials’ thermal properties on the internal dry bulb temperature. Observation showed that the room with no exposure to solar radiation has the coolest internal day and night peaks and temperature, whereas the more the solar radiation hits the external envelope the more the room is warmer.

The source of energy requirement for summer indoor cooling is based only on electricity. Figure 6 shows an overview of the current situation. The effect of the high internal temperature required an average of 50 kWh of daily electricity consumption in order to decrease the internal dry bulb temperature in only three rooms which constitute 58 sq. m. This leads to energy consumption of 0.86 kWh/m² (for each m²). Whereas, projecting this number on the studied house which is 150 sq. m if it was totally cooled during summer will end up by consuming 129 kWh daily electricity (multiplying the energy consumption of each m² by the total house area).

Given that the thermal performance of the house was directly affected by the solar radiation and the absorbance of the external envelope. Therefore, the model simulation depends mainly on installing shading elements and enhancing the external envelope’s thermal properties to reduce heat gain to help the cooling process.

In the enhancement of the current situation thermal and energy consumption of the studied house, the construction
is altered to insulated construction method to increase thermal resistance and minimize heat loss. In addition to these alterations, an increase in the ventilation also was proposed to regulate the internal temperature was also simulated. Also, louvers were installed on the eastern, western, and southern façade.

To begin with the construction materials enhancement, the first material was the windows’ glass which has been changed from a single-glazed to double-glazed material. This reduced its U value from 5.6 W/m²K to 2.9 W/m²K. The difference is 52% making the simulated house reduce heat gain through windows. In addition, the envelope construction materials were limestone plaster and painted from the inside. A thermal barrier and an insulation layer from the outer side were placed to reduce the U value and increase the thermal resistance of the construction materials used. Therefore, the U value was 3.9 kWh/m²/year and was enhanced to reach 2.4 kWh/m²/year which is 62%. Furthermore, the roof was also enhanced, where it was a 15 cm reinforced concrete roof. Thermal insulation was added on top of the slab with a 50 cm earth to have a green roof. This enhanced its U value from 5.4 kWh/m²/year to 1.3 kWh/m²/year. By this, elimination of solar radiation to hit the roof surface.

In addition, shading devices were added on the elevation to prevent solar radiation to hit the external envelope and transfer heat to inside and increase the indoor temperature.
By doing such enhancements and changes and according to the simulation software, the energy use intensity (EUI) of the house was reduced 56% from 506 kWh/m²/year to 222 kWh/m²/year (Figure 7). Insight 360 gives results in EUI (Energy Use Intensity) per unit of the built area. It means that this software provides an evaluation of the building’s annual energy consumption according to the gross floor area. This process is applied to all types of energy used in the building, such as space heating, and space cooling. For this reason, these measurements should be taken into consideration while selecting the external envelope building’s material according to the benchmark set by Insight 360, which is ASHRAE 90.1.

Figure 7: Simulated data showing the Daily, Cumulative Energy Consumption, and EUI. Source: Author

Figure 6 shows the positive impact of minimizing solar radiation contact with the external envelope and enhancing the house envelope thermal components on both the electricity consumption and the energy use intensity. Furthermore, it shows the impact of the reducing cooling load. The values of the above for the indoor cooling electricity consumption changed from 350 kWh as an average in a warm and hot week to 194 kWh after the retrofitting enhancements. While for the EUI, it dropped from 506 to reach 222 kWh/m²/year which is a decrease of 56%. The benchmark set by Insight 360 is 257 kWh/m²/year.

Concerning the energy collectors, the main data are reported in Table 1 to achieve net zero energy. It includes the needed months for electricity generation and the needed solar panels’ units for the amount of cooling load of 12 panels which is equal to 25 sq. m. The simulation of the house allowed an accurate insight into the potential of reducing summer cooling load and achieving full indoor cooling according to two main factors: thermal transfer from walls and roof, and direct gains from sunlight through windows.

The external envelope varies considerably within the different parts of the house which are affecting the needed energy for indoor cooling. Whereas, whenever the house area increase, the cooling load increase. Accordingly, the need for solar panels will increase. The energy simulation of the house indicates that retrofitting could achieve a sufficient energy status by enhancing the envelope’s thermal properties and using the roof only for electricity generation, under the given climate conditions.

**Conclusion**

This research made an investigation into all aspects of heavyweight thermal mass stone house type and the impact of retrofitting a stone house type through data recording of the internal dry bulb temperature and through software simulation in the warm Mediterranean coastal area of Lebanon reaching the following key conclusions: The first factor deals with enhancing the thermal properties of the external envelope can decrease energy consumption and cooling load. The second factor is to incorporate shading devices to protect the envelope from direct solar radiation. These two strategies showed that 56% of cooling demand could be reduced. Last but not least, eliminating the use of scarce non-renewable energy and depending on photovoltaic solar panels to achieve the needed electricity for summer indoor cooling. Results showed that 25 sq. m of solar panels are required to mitigate all the required energy.

**Table 1**: Calculation of the needed solar panels to generate the needed energy for summer indoor cooling. 
*Source: Author*

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<thead>
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<th>Panels Needed</th>
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<th>Months</th>
<th>Solar Angle for Beirut</th>
<th>Mean Irradiance of Global</th>
<th>Mean Irradiance of Gobal</th>
<th>Efficiency %</th>
<th>Coef</th>
<th>Total Monthly Generated</th>
<th>Panels Needed</th>
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<td>369</td>
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<td>9,332</td>
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<tr>
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<td>4,704</td>
<td>1.689</td>
<td>7,611</td>
<td>1.218</td>
<td>36,535</td>
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**References**

Ali Ahmad, Muzna Al-Masri, Hassan Hrajli, Alex Chaplain, Jamil Moawad, et al.. Models for tackling Lebanon’s electricity crisis. 2021


