Financial Aspect and Practicability of Converting Existing Buildings to nZEB

Case Study in Cairo, Egypt

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Abstract. Financial feasibility of a project is a strong indicator of whether the project will be accepted by different stakeholders of the building or not. This research aims at analysing the financials of converting an existing residential building to net zero energy building. On a case study building, specific retrofit actions are selected, specific PV system is considered and a complete cost analysis is performed based on market available materials in actual prices in the Egyptian market. The research utilizes energy simulation to compare the amount of energy saving between the current and retrofitted cases of the case study building. Actual electricity bills are used to calculate the electricity usage of the building. Similarly, actual solar energy pricing is considered in order to evaluate the feasibility of the conversion. The pricing of the retrofit actions using market available materials is calculated as well. The return on investment study shows how applicable the conversion is.

Keywords: nZEB, financial feasibility, retrofit, PV panels

1. Introduction
The increasing energy consumption rates and the accompanied greenhouse gas emissions are considered one of the world’s greatest concerns recently. The total energy sold in Egypt for the year 2014 reached 120 terra watt hour with an annual average growth rate of 5.2% [1]. The building sector alone -including all building types- contributes with 40% of total energy consumption and one third of greenhouse gas emissions globally. The numbers are even higher in Egypt, reaching 51% of total energy sold in 2014 [1], [2]. For this reason, the building sector represents a large potential for significantly reducing both the energy demand and the harmful emissions.

Among the relatively new strategies that have been practiced all over the world in the last few years is Net-Zero Energy Building concept. This concept aims at designing greener buildings in terms of energy usage. Converting an existing building to NZEB is adopted by this paper as a contribution to solving the energy problem. The financial aspect of this conversion is the main concern of the study, where the cost estimation is calculated and a return of investment is predicted.

2. Literature review
One of the sources that provide energy breakdown data in Egypt was a study that surveyed the electricity usage in an urban community in Cairo. The study revealed that 74% of the electricity used is consumed towards reaching thermal comfort, where 65% goes to cooling purposes while 9% goes to heating ones [3]. This shows the importance of solving the thermal comfort aspects and proves that if the building insulation efficiency was enhanced, the energy saving will be significant.

Buildings in Egypt are generally characterized by low levels of insulation from what leads to a very poor thermal performance and low indoor air quality. A survey conducted in 2012 revealed that the building
envelopes of the surveyed buildings -1500 apartments- were not airtight, all the openings were single glazed, walls were not insulated and no shading treatment was provided. To compensate for this technical problem, 80% of the apartments installed at least one air-conditioner unit, and this leads to the peak electric loads that causes failure and complete shutdown of the grid, as experienced recently in Egypt. It is worth saying that the final survey findings showed that the use of air-conditioners raised the annual electricity bill by a range of 44% to 57% in Cairo [4].

The state of the art for nZEBs in Egypt shows a lack of studies in this scope. A research tackled this conversion but for vernacular architecture and the results of this study showed that combining vernacular passive strategies with roof top solar panels results in a hybrid energy efficient retrofitting solution for off-grid vernacular buildings [5]. The nZEB concept is not well-introduced in the Egyptian context; professionals are not familiar with the term, not to mention users. This is why this paper is considered a novel experimental study in the given context, as the only found source does not address the climate or the building type in the capital; Cairo. Moreover, the nZEB concept is widely studied in countries with cold climate conditions and, it is barely tackled in hot arid climates like Egypt. Since the Egyptian environment has a high solar potential and the buildings are mostly un-isolated, then the retrofit scenario accompanied by the PV plant represents a valid solution to the problem. Proposing a scenario for converting a common building to an nZEB and supporting it with a financial study can have a positive effect on both introducing the concept to the community and promoting for the idea.

3. Methodology

The methodology addresses the retrofit strategy with emphasis on the envelope material upgrades as well as a PV plant as a source of renewable energy for the conversion process. The research suggests using energy simulation and the utilization of the nZEB (net zero-energy buildings) guidelines in order to calculate cost estimation. The study uses a practical approach to test the applicability of the assumption using actual electricity prices, market available materials, as well as actual suppliers for the PV system. Working on hands-on already existing building with its real data and circumstances gives the study a pragmatic logic. This makes the study more of an experiment with rigid results than a theoretical hypothesis. The study provides a complete cost analysis and return on investment for the NZEB transition process. The methodology uses market-available materials with its actual prices in the Egyptian market. This is meant to support the practicability and improve the validity of the experiment, which in turn reflects on the previously mentioned goal of promoting to the concept in the Egyptian context.

4. Building data

The case study building is a five storey residential building with two apartments per floor each of an approximate area of 140 m² and total surface area of the building is 350 m². The building has one staircase and one elevator acting as the core vertical circulation, and its orientation is North-South. The typical floor plan for the prototype is as seen in figure 1. The building is located in an average residential community in Nasr City area in Cairo, Egypt.

The most important data to be considered in this case is the energy consumption data because it has a direct impact on the amount of energy to be saved either through retrofit or to be generated by the renewable energy system. An average consumption of the monthly rates was detected as seen in figure 2 from the actual electricity bills of the case study building.
The total average electricity consumption per apartment is 6,206kWh/year. The mentioned apartment is the one with the largest consumption due to the number of inhabitants; 3 adults and 3 children, so taking the average based on the bills of this particular apartment acts as a worst case scenario for maximum consumption. In order to calculate the electricity consumption for the whole building, the 10 apartments have to be considered: 62,060kWh/year approximately 62,000kWh/year.

5. Envelope retrofit

The building’s status quo shows low thermal insulation and bad performance of envelope elements. Accordingly, retrofit actions towards window section and glass reflectivity, wall insulation, and roof insulation were determined. Pricing of each element as well as the applicable area were calculated as follows:

5.1. Window section

The window section currently installed is single glazed with poor insulation, so it would be replaced by a double glazed section of 6mm each with 10mm air gap in between, as seen in figure 3.

- Glazing area per apartment=12 m² (for 6 windows)
- Glazing area for whole building=120 m²
- Price per m² = 2400 LE
5.2. Window film

The windows will be protected using film coating as shown in figure 4. The amount of energy saved for every 100 square meters of glass retrofitted with energy-saving films, a building’s energy needs is reduced by up to 10,600 kWh per year which is comparable to reducing its CO₂ emissions by about 9,500kg [6], [7].

![Figure 3. Retrofit window cross section.](image)

![Figure 4. Retrofit window film.](image)

- Total windows area = 120 m²
- Total frame area = 18 m²
- Net glazing area = 120 – 18 = 102 m²
- Price = 268 LE/m²

5.3. Wall insulation

To enhance the wall insulation, a material composed of compressed polystyrene thermal insulation boards as seen in figure 5 was chosen. The material comes in the form of sheets (250x60cm) thickness ranges from (0.4 - 10 cm) the chosen thickness is 2 cm. It can be covered by paint or wallpaper, and they are installed using cement mortar [8].

- Total building circumference=1,275 m²
5.4. Roof insulation
Similar to the wall insulation, foam tiles of 30x30cm dimensions and thickness of 2.5cm are applied to the flooring of the building roof, see figure 6. This material is characterized by its high thermal resistance from what reflects on its energy saving potential. Also, water absorption by submerging is negligible and this is why it is suitable for rooftops. It is available in plain grey color or patterns and it can be easily installed using cement mortar [9].

6. Simulation
For the retrofit actions to be verified, energy simulation needs to be performed. Using DesignBuilder software the electricity consumption of the existing building with its current situation is performed. The retrofit actions are then simulated in order to be able to measure the difference in electricity consumption between the two cases.

6.1. Current situation simulation
By comparing the annual electricity consumption as seen in figure 7 to the actual amount calculated from the building electricity bills, an amount of 66000 kWh was simulated while an amount of 62000 kWh was the actual consumption. It is found that the percentage of variance is almost 5%.

6.2. Retrofitted situation simulation

By comparing the annual electricity consumption as seen in figure 7 to the actual amount calculated from the building electricity bills, an amount of 66000 kWh was simulated while an amount of 62000 kWh was the actual consumption. It is found that the percentage of variance is almost 5%.

Figure 7. Current case annual simulation results. Figure 8. Retrofitted case annual simulation results.

7. Simulation conclusion

After considering the envelope retrofit actions the annual electricity consumption is decreased to 44000 kWh instead of 66000 kWh in the current existing case. This shows the impact of the retrofit technologies used and gives a base for the PV system design to work on.

Energy consumption before retrofit = 66,000 kWh
Energy consumption after retrofit = 44,000 kWh
Energy saving = 22,000 kWh

8. Renewable energy design

8.1. Design basic data

- Location: Nasr City, Cairo, Egypt
- Global Horizontal irradiance GHI: annual average = 5.4 kWh/m2/day
- Building average consumption: 24 kW
- Maximum power needed: 12040 kWh during August

8.2. Panels’ basic data

- The panels’ orientation: panels will be installed facing south direction based on the solar data analysis.
- The panels’ inclination angle: 30 degrees.
- Type of panels will be poly crystalline type because it generates the largest amount of energy in the Egyptian circumstances.
- The spacing between panels in order to avoid surplus shading of the panels on each other was calculated that if the tilting angle was 30 degrees, then a space of 60 cm must be between each row of panels and the one preceding it [10], [11].

8.3. Panels’ distribution

After deciding the tilting angle, the orientation and the panel type comes the panel design phase. Figure 9 shows the proposed panel distribution including the maximum number of panels that could be installed on the building roof.
9. Cost analysis

9.1. Envelope retrofit
For each of the retrofit technologies that were discussed in the retrofit technologies section, the amounts are multiplied by the prices in order to give the total cost. These results are shown in Table 1.

9.2. Renewable energy cost
For the PV system to be calculated, the amount of electricity resulted from the simulation is used (44,000 kWh). Knowing that every 1 kW power station generates 1800 kWh/year, and then the building will need a 24 kW station (44,000/1800). As stated by the supplier, for each 1 kW power station 4 panels and a surface area of 10 m² of plane roof is needed and it will cost 15,000 LE [12]. The rest of the calculations are shown in Table 2.

10. Electricity consumption cost
In order to monitor the benefit of this transition, the cost of electricity consumption has to be calculated. Based on the electricity bills of one apartment, and by multiplying each value of consumption to its equivalent price –as stated by the Egyptian laws- the yearly electricity consumption for the year 2018 is as follows:

| Month | KW  | LE  |
|-------|-----|-----|
| Jan   | 615 | 553.5 |
| Feb   | 252 | 176.4 |
| Mar   | 163 | 58.68 |
| Apr   | 162 | 58.32 |
| May   | 225 | 157.5 |
| Jun   | 655 | 884.25 |
| Jul   | 734 | 990.9 |
| Aug   | 1204 | 1745.8 |
| Sep   | 1061 | 1538.45 |
| Oct   | 567 | 510.3 |
| Nov   | 296 | 207.2 |
| Dec   | 272 | 190.4 |
| Total | 6206 | 7071.7 |

Table 2. PV station cost calculation.

| Item                                                      | Quantity | Unit price     | Description                        | Overall price |
|-----------------------------------------------------------|----------|----------------|------------------------------------|---------------|
| PV on-grid system (after retrofit)                        | 96 Panels| 15,000 LE/ 1 kW(24 kW needed) Polycrystalline PV panels | 360,000 LE    |
Form the table above, it is clear that each apartment pays around 7,000 LE per year. This data will be used in the return of investment calculations in a following section.

11. Cost analysis conclusion
The proposed retrofit actions can reduce the electricity consumption by 22,000 kWh annually from what enhances the energy performance of the building as a first step of reaching nZEB. The size of the PV system to be used to cover the rest of the consumed electricity is 24 kW/year station. The overall cost for the building to be converted to nZEB can be calculated as follows:

- Envelope retrofit = 566,936 LE + PV system = 360,000 LE
- Total price for the whole building = 926,936 LE approximately 927,000 LE
- Apartment’s share = 92,700 LE

On the other hand, the cost of electricity consumption that will be saved by the transition is around 7,000 LE per year per apartment.

12. Return on investment
The return on investment analysis shows how much time is needed for the owner to get the money that they invested back. In order to provide this properly, some aspects should be considered. One of these aspects is the fact that electricity prices increase yearly in Egypt with a percentage of roughly 10%. Accordingly, to calculate the amount of saving for the first 9 years would be 95,000 LE which will cover both the expenses of both the retrofit and the PV panel station.

Other aspects cannot be integrated within the equations because they cannot be translated to monetary values. For example, the thermal comfort which reflects on the wellbeing of the users and their productivity. Also, the decreased usage of air conditioning units and heaters will result in less maintenance costs and longer lifetime for these appliances. Similarly, the lifetime of the PV plant is around 20 years, so the owner will enjoy free electricity for more than 10 years after the payback period ends.

13. Conclusion
The outcome of the research combines both retrofitting and renewable energy strategies to convert existing residential buildings to nZEBs. An nZEB building was reached using envelope retrofit and PV panels on a case study building. The results of the financial study shows that the conversion is feasible and the return of investment is adequate compared to the current price of electricity. Any given existing residential building can follow the same guideline proposed by the paper, and calculate the return of investment for the circumstances of the building.

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