IMPACT AND POTENTIALS OF COMMUNITY SCALE LOW-ENERGY RETROFIT: CASE STUDY IN CAIRO

Shady Attia.[1*]
André De Herde[1]

[1] Université Catholique de Louvain, Architecture et Climat,[*] shady.attia@uclouvain.be

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Abstract

There are extraordinary opportunities to reduce the consumption of fossil energy as a result of retrofitting the existing buildings in Egypt. For instance, Cairo falls in the arid climate zone with an annual total radiation above 2409 bankable kWh/m^2 per annum with approximately 3300 hours of full sunshine. However, the poorly insulated fabric of most buildings shows relatively high demand for cooling and heating energy.

To overcome this problem and to examine these opportunities, this study evaluates the retrofit of a middle-income urban residential case in Cairo. The aim of the study is to investigate the potentials and impact of retrofits on two different scales. The first is on the building scale, intending to reach a low-energy performance. The second is on a community scale, intending to increase the dependence on renewable sources.

The case study employed TRNSYS to evaluate the performance and energy/carbon emissions savings. The research took in consideration passive and active design strategies such as envelope retrofit, internal loads reduction, and natural ventilation; in addition to domestic water heating, photovoltaic panels and solar thermal air conditioning.

The results were evaluated to assess the suitability of each strategy based on energy performance. The final result of this study shows the feasibility of improving the envelope performance and installing solar hot water collectors and solar thermal air conditioning. The low-energy retrofit for old residential buildings leads to significant savings in energy consumption when applied on community scale rather than building scale. However, it is urgent to set energy conservation and code-enforced retrofit measures to start a national retrofit process.

1. Introduction

"*People are drinking electricity, exactly like water*." This was the statement of the Egyptian minister of electricity describing the increasing electrical consumption for residential housing, in 2008. Despite the low electricity consumption rates in Egypt (1120 kWh/capita in 2002), when compared to Northern Mediterranean countries, electricity consumption for residential purposes increased by 12 % in 2007 (Michel and Elsayed 2006). In summer 2008, the total electric demand peaked to 21,530 MW, compared to 19,250 in 2007. Consequentially, most governorates, especially in Upper Egypt, witnessed daily blackouts ranging from 5 to 8 hours.

Analysts confirm that since the beginning of the long hot summers in the last decade, the hot seasons have been extended from April to October. As a result, more than half of the urban peak load of energy consumption is used to satisfy air conditioning demands alone. In 2008, annual sales of air conditioners (AC) reached 150,000 units. Consequently, air-conditioning of buildings became the single largest consumer of electricity and it accounts for nearly 60% of nation's peak power demand and over 30% (6,500 MW) of annual energy consumption in the residential sector. This demand is expected to grow annually by more than 12% ((ME 2006/2007; Georgy and Soliman 2007; ME 2007).

1.1 Retrofitting as a Solution

Therefore, implementing energy effective retrofitting schemes, on a community scale, is the main issue to reduce the energy used in housing for cooling. In this research, the main focus is to balance occupant comfort, and to reduce the electric consumption. The reduction of electric consumption also will reduce building peak demand which most directly benefits the electric utility and the consumer.

For long time the Egyptian built environment lacked and is still lacking of energy regulations. In an attempt to reduce growth in demand for electrical energy, the government issued the first Egyptian Energy Efficiency Building Code (EEEBC) for residential buildings in 2004 (HBRC 2005). However, the code is not mandatory and the government was unable to adopt and enforce the new code until now. Adding to that, there were no guidelines provided in the code with regard to retrofitting existing buildings. For all that reasons, this study was conducted to assess the impact and potentials of retrofitting existing buildings, on a community scale with low energy conservation measures. The emphasis was placed on residential middle-income housing since it has considerable potential for energy conservation measures that should start at once (Hussein 1995).

1.2 Objectives

The objectives of the study were to investigate theoretically and experimentally the potentials and impact of retrofits on two different scales. The first is on the building scale, intending to reach a low-energy performance by using active and passive design strategies such as thermal insulation, efficient glazing systems and solar applications. The second is on a community scale, intending to increase the dependence on renewable sources. A sample community in Cairo was selected as a case study. The case study employed TRNSYS to model and evaluates the performance of different options and retrofit techniques.

2. Case Study: Madinat Al Mab’ussin in Cairo

Madinat Al Mab’ussin (MAM) is a residential community located in the centre of Cairo, 2.5 km west the Nile. The weather patterns in Cairo are characterized by being extremely hot and dry (Group B, according to Köppen Classification). Average annual precipitation is 11mm; average daily temperature during July is 35.4 ^{o}C; summer temperatures above 40^{o}C are not uncommon and often temperatures rise above 39^{o}C. Average summer relative humidity is 62%. For this study, climate data were obtained from the Egyptian Organization of Meteorology (EOG).

2.1 Community Description

MAM community was built in 1976 on an agrarian land to inhabit the academic staff of Cairo University located nearby. MAM has a rectangular layout, stretching 320 m from the east to the west and its height is 220 m as shown in figure 1. The community consists of 29 multi-storey apartment blocks.

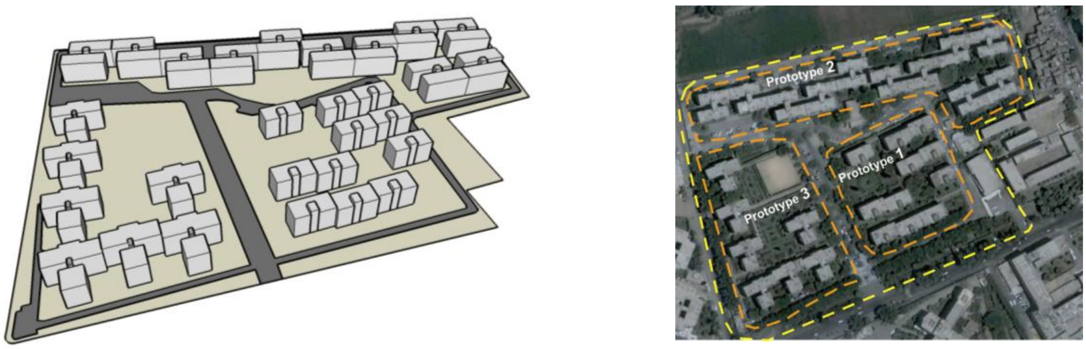

Fig 1a. 3D model of MAM with blocks clustering, 1b. MAM layout with three different prototypes blocks

Table 1a, list the three different prototypes in detail. All blocks are five floors high and are elongated along an east-west axis. All buildings are built having (fig 2a&b) a concrete structure and brick walls without thermal insulation. There is no solar protection for the facades and most wooden windows are draughty. Table 1b, lists the general description of the sample building and some properties for the construction sections used, respectively.

Table 1a. Blocks description, 1b. basecase building description

	Prototype 1	Prototype 2	Prototype 3
Blocks	11	7	11
Apartments per block	2	3	4
Number of apartments	22	21	44
Apartments area	105 m^2	100 m^2	95 m^2

Base case building description	**Prototype 1**
Shape	Rectangular (12 m x 8 m)
Height	3 m height per floor
Volume	288 m^3
Wall area	120 m^2
Roof area	96 m^2
Floor area	96 m^2
Windows area	12.24 m^2, 34% of total wall area
Exterior Wall U-Value	1.78 W/m2 ^{o}C
Roof U-value	1.39 W/m2 ^{o}C
Floor U-value	1.58 W/m2 ^{o}C

Fig 2a, Prototype 1 includes two apartments per block, b.North and south facades of prototype block 1

2.2 Occupants

In average, each apartment consists of four to six occupant family. Apartments are generally empty during the day and occupied after 3 p.m until 8 to 9 a.m in the next morning during weekdays and 24 hours a day during most weekends. In addition to ceiling fans, almost all occupants installed more than one AC unit (split or window) for cooling. All apartments are equipped with electric water heaters and have at least one mobile electric space heater. Also more of half of the apartments replaced their windows by new aluminum profile windows.

3. Methodology

In order to achieve the objective of this research, the following methodology was used:

- Establish desirable comfort conditions
- Conduct a field survey to : (a) mark typical apartment description and construction materials in addition to (b) estimate the typical electric consumption rate per apartment
- Select typical apartment blocks and set major parameters for the base case building
- Run dynamic simulations of base case and calibrate it in regard to the field survey results
- Run dynamic simulations of different retrofits including passive and active design strategies on buildings and community scale
- Comparison of the predictions of the simulations for the retrofitted and base case

3.1 Thermal Comfort Criteria for Cairo

Achieving thermal comfort in hot arid climates requires the knowledge of the maximum internal air and surface temperatures that could be tolerated before having to provide supplementary cooling. Figure 3.b shows a simplified psychometric chart as quantified by the ASHRAE (ASHRAE 2005). In Cairo, the comfort zone may shift slightly to the right, about 3 degrees C, as indicated by the dark blue oval, because Egyptians are more comfortable at higher temperatures. Also in a country like Egypt people are used to acclimatization. People tolerate more variation in thermal conditions, and are comfortable over a wider range of temperatures. Acceptable indoor air temperature for Cairo, range between 24 degree C and 29 degree C, with relative humidity between 20% and 50% and air velocity 0.5 to 1.5 m/s (HBRC 2005) (Medhat and Khalil 2004). When temperatures fall below 23 degrees C, solar exposure is desirable; above 31 degree C, cooling is required for comfort. The solar radiation is desirable in most of December, January and February, as well as in the morning and late evening in November, March, April and May. Conversely, cooling and air movement, in lower humidity conditions, are needed during midday and afternoon hours in May through October.

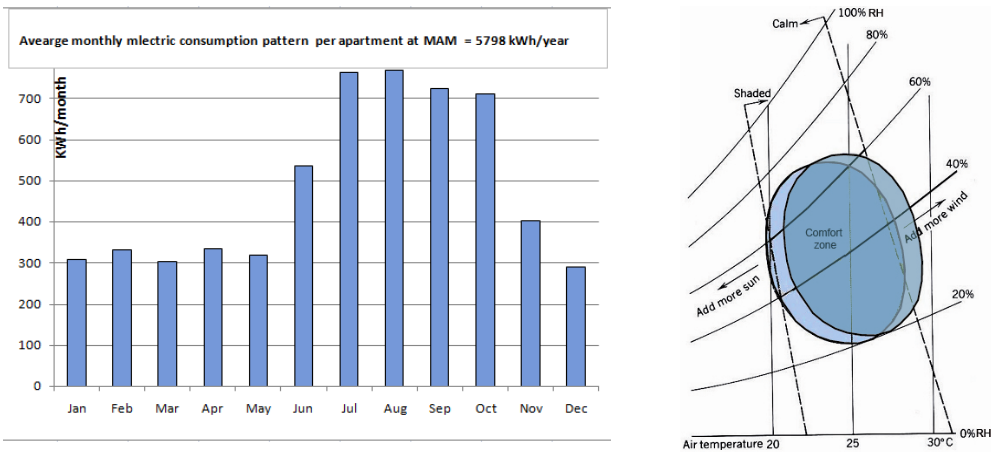

Fig. 3.a, Typical monthly electric demand for apartments in MAM, b. Psychometric chart for Egypt (ASHRAE)

3.2 Average Annual Electric Consumption

In Egypt, there are no existing energy indicators in use. In MAM, the main energy source is electricity while gas canisters are used for cooking. Therefore, the indicator that is most easily communicated for this study is kWh per square meter floor area. Also, electrical load was considered because of its direct impact on the nation's peak electrical demand. A field survey was conducted in MAM by the author to estimate the average annual electric consumption for all apartments. Figure 3.a illustrates the monthly kWh consumption for the 87 apartment. The data was anonymously obtained from the occupants and verified by the electric utility company for the year 2006-2007.

3.3 Base Case and Calibration

In the study approach, three sample blocks were selected, representing the three different prototypes of apartment-blocks. The three blocks were referred to as the base cases (prototype 01, prototype 02 and prototype 03) to represent a reference point for the energy analysis. The properties of the construction materials are listed in Table 1b. The three base cases were simulated using the TRNSYS building simulation program. Simulation was conducted to determine the building annual energy consumption and the peak load. Several iterations took place to match as possible the field survey for electric consumption. A typical meteorological year (TMY) of climate data in Cairo was considered for simulations.

4. Energy Retrofit Strategies

The research developed various passive and active retrofit strategies such as envelope retrofit, efficient solar protection, high thermal inertia, and hybrid ventilation strategies; in addition to domestic water heating, photovoltaic panels and solar thermal air conditioning. The following strategies can be divided into two, different parts. In the first part, the strategies are applied on the building scale (4.1-4.4) and the second part the strategies are applied on an urban scale (4.5-4.6).

4.1 Envelope

The first step that can reduce heat gain significantly is to install a thermal insulation. In Egypt, applying thermal insulation of extruded polystyrene, on the outside of the building, is the most appropriate to keep the space of the existing living area. Also because extruded polystyrene is widely produced in Egypt and exhibits good characteristics with respect to its durability and resistance to moisture transfer, and since the weather in Egypt is mostly dry, no vapor barriers are used. To comply with the EEEBC, the thermal resistances (R-values) were 0.90 and 2.3 $m^2\ {}^oC/W$ for wall and roof sections, respectively (ECP306-2005). Also thermal bridging through typical window systems was found to be considerable and therefore should be taken into account energy conservation (Ben-Nakhi 2002). As part of the retrofit plan, edge insulation for window systems are proposed to minimize thermal bridging in the buildings of hot regions.

4.2 Solar Protection & Openings

The existing building openings do not have any solar protection devices to reduce the solar gains during the summer season. Therefore all single pane windows will be replaced with 2.5 R double-pane windows with an air layer thickness of 6mm. Since no windows face either east or west, only south-facing windows will have internal and external solar protection in addition to low-e glazing. External overhang shading devices should admit low angle sun in the morning or winter when heat is needed screens sun in middle of the day and in summer when overheating is a risk. The shading coefficient after the retrofit is 0.3. The air tightness of all openings should meet the EEEBC that set a limit of 1.7 L/s m^2 for the envelope.

4.3 Ventilation

During spring and autumn, passive cooling can be provided as an effective retrofit strategy. Passive cooling could be simply achieved through diurnal only when indoor comfort can be experienced at the outdoor temperature. Passive cooling could be also achieved through nocturnal ventilation only in high mass building and when the daytime temperature is below 36^oC (Givoni 1992). Nocturnal ventilation removes the heat accumulated during the day and lowers the mean internal air temperature. The existing apartment's orientation allows air to flow through at night and when outside temperature is lower than inside the building. Assuming that internal doors are kept open most of the time, a free flow for cross ventilation will be allowed.

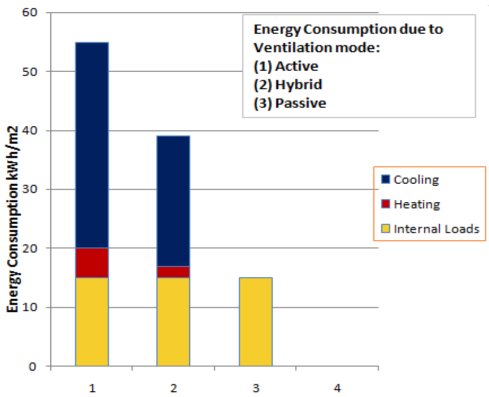

Fig 4, Comparison of energy savings due to different ventilation modes

The retrofit scheme suggests that all windows include movable wooden shutters for the same purpose. However, in order that the building operates in passive or hybrid modes identifying a synoptic room set point temperature is not possible. Rather an annual analysis was made using representative annual climate and operating data (De Dear and Brager 2002). The climatic data was assessed in relation to comfort conditions using Givoni's Building Bioclimatic Chart 1992 (Givoni 1992). Results of dynamic simulations showed (fig.4) that more than 33% energy was saved when the apartments where retrofitted using hybrid ventilation strategies when compared to fully air conditioned basecase.

4.4 Occupancy, Internal Loads and Equipment Efficiency

Occupant's behavior is influencing energy consumption in MAM. The influence of occupant's consumption patterns has a remarkable national character. Since the occupant density is fairly high; whereas occupant's number per apartment is five in average and there are in average three AC units per apartment, optimizing the operation pattern is essential for the retrofit plan.

In order to understand the occupancy pattern and operation schedules of electrical appliances were included in the field survey. The field survey result classifies the major appliances in each home as follow: three AC units, 20 liter electric resistance water heater, a refrigerator, a washer machine. Several occupants have added a chest freezer. Lighting in the apartments is of the conventional incandescent type. Typical appliances include a ceiling and standing fan each in living and bedroom, personal computers, microwave oven, video cassette recorder, television, and stereo.

The field survey showed also that electricity is not used rationally probably due to the subsidized electricity prices (0.02 US$ per kWh for residential housing). For instance, AC thermostat was set around 22^{o}C and was left for continues operation. Lights are often left on even when rooms are vacant. The most paradoxical phenomena was also leaving the windows open while AC are running. In order to solve this problem, the retrofit plan suggests a plan for raising the awareness of users and encouraging them to install energy rated and efficient equipments. In addition to encouraging them to consume consciously and change their attitudes for instance having intermittent operation for AC and try to reduce the peak load demand by avoiding running equipments together. All the above mentioned strategies are seeking to reduce the consumption and employ equipments efficient as possible.

4.5 Solar Thermal System

For domestic hot water (DHW), several choices are available. However, for the case of MAM, using a unified thermal solar collector system that serves all apartments per block is a practical solution. A market survey determined the selection of drain back solar system. The 36 m^2 solar collectors are connected to a 1500 L storage tank mounted on top of the flat blocks roofs. The panels will be installed on the roof and inclined to the south with a tilt angle of 42^{o} from the horizontal. The system will be turned off during the summer, while the existing electric water heaters will be kept for instantaneous back up.

4.6 Solar Electric System

The intensity of sunrays in Cairo is as high as it is a part of the Sahara, making Egypt, a magnet for solar harnessing. In MAM, we get 2409 bankable kWh/m^2 per annum. Therefore, PV panels are part of the active retrofit strategies. A 110 m^2 PV installation on the roof of each block will have a nominal output of 14.7 kWp producing approximately 10,000 kWh/a. This equals approximately 1000 KWh/a per apartment. The panels are made of polycrystalline cells (module efficiency 10.5%) and can be mounted on the flat roof with 29^{o} inclination.

5. Results and Discussion

5.1 Energy Performance Analysis

All retrofit strategies were integrated in the new simulation model representing the three retrofitted prototype apartments. The results from the TRNSYS program were analyzed to produce the data shown in figure 5. The annual electrical consumption per square meter floor area was performed to demonstrate the effect of different retrofits including passive and active design strategies on buildings and community scale.

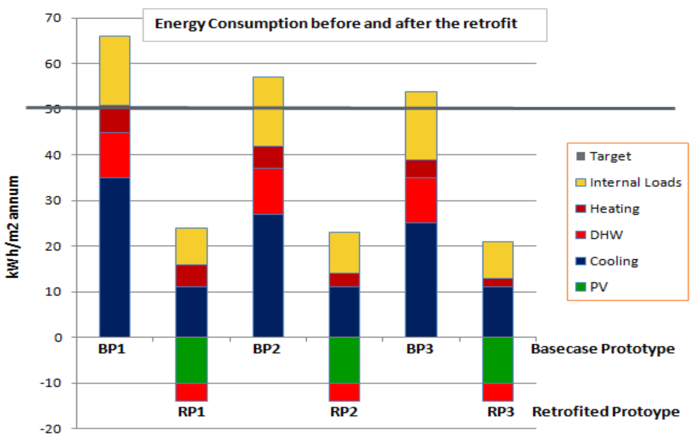

Fig 5 Energy consumption before and after

The passive strategies of retrofit achieved up to 55 percent reduction in electric energy demand. For the three different examined apartment blocks, energy use was reduced to between 30 and 40 $kWh.m^2a$. After that the active strategies can deliver up to 60 percent of the required energy after implementing the passive retrofit strategies. More importantly, the combined strategies of retrofit achieved up to 83 percent total reduction in electric energy demand. For the three different examined apartment blocks, total energy use was reduced to between 48 and 57 $kWh.m^2a$. The passive and active retrofit strategies did not only save energy, they also improved the comfort and living quality, extended the life period for at least 40 years, as well as increasing real estate value.

5.2 Retrofit Potentials: Low Energy & Community Scale Solar Applications

The retrofit achieved up to 83 percent reduction in electric energy demand. There is a great potential for housing retrofit in Egypt even though that the average electricity consumption per capita in MAM is 1159 kWh/person for the year 2000. This figure is not high when compared to consumption figures in Northern Mediterranean countries. In fact, the study showed great potential for the retrofit not only on the level of energy consumption reduction, but also on the level of CO^2-emissions reduction. Before the retrofit, apartments consumed in average 5798 kWh/a, which is equivalent to 9566 $KgCO^2$-emissions. After the retrofit, apartments would consume in average 2400 kWh/a. More than half of it will be delivered by solar thermal and electric panels (1300 kWh/a). Given that, CO^2-emissions will be reduced to 1815 $KgCO^2$-emissions.

In general, the growing increase in electricity consumption rates for cooling requirements are extremely high and as long the energy performance of the whole building is very poor, there are great benefit from retrofit. However, the main challenge that faces architects and engineers is that the Egyptian Code did not define a fixed maximum kWh/m^2 per annum for newly and retrofitted building types. The only country in the region that developed a code was Kuwait, specifying a limit of 22 $kWh/m^2.a$ for air cooled housing and 16 $kWh/m^2.a$ for water cooled housing (Al-Ragom 2003). Therefore, it is necessary to set a value for residential low energy retrofits, expressed in $kWh/m^2.a$, in addition to enforcing that value through the code.

Morevover, modeling and simulating the performance of solar electric and solar thermal applications yielded very encouraging results. For instance, the simulations showed that using a centralized solar thermal system for DHW for each apartments block is 100% rewarding. A centralized system for DHW is an easy shift to renewable energy production. The use of a centralized system for DHW might be expanded to other applications such as centralized solar thermal energy for air conditioning which could replace the AC units system in the future. Especially when we take into account that air conditioning requires roughly 4.5 times the energy of heating. Recent publications indicate that solar thermal energy could be stored and concentrated which can allow utilities to store steam for six hours. Heated steam could be used to generate electricity to consume during period of peak demand (Koldehoff 2008).

5.3 Retrofit Challenge

Despite the success of the retrofit strategies in saving energy and improving comfort, depending on AC units for cooling is not efficient or sustainable. Depending on AC units requires enormous energy and will frequently lead to electric blackouts every summer due to feeding from the grid. The reason of that is the seasonability of electricity consumption. As long cooling is depending on the electric grid, there will be always daily or weekly or annually consumption extremes in proportion to weather extremes. In the case of Cairo, the split or window units cause also air quality problems, carrying streams of bacteria and fungus of the cooled air and vomit hot air back in the far hot outdoor environment. It is a vicious circle; the hotter it gets outside the more heat AC's must pump out from inside, increasing the heat island effect, reducing the AC's efficiency and forcing the consumption of more electricity. Therefore, switching to solar thermal or solar electric air conditioning is crucial to break this circle for the future.

6. Conclusion

This study presented passive and active renovation strategies for an existing residential community in order to evaluate the impact and potentials of low-energy retrofit. In this way, the study is deliberately forward looking, evaluating and assessing the energy potentials and feasibility providing an examination and vision for retrofits that may soon be implemented.

The combined strategies of retrofit achieved up to 83 percent total reduction in electric energy demand. For the three different examined apartment blocks, total energy use was reduced to between 48 and 57 $kWh.m^2a$. The passive and active retrofit strategies did not only save energy, they also improved the comfort and living quality, extended the life period for at least 40 years, as well as increasing the real estate value. However, the Egyptian Code should define the maximum energy consumption values for low-energy retrofit.

The success of the solar thermal system for DHW can be expanded to other applications such as solar assisted cooling. Designing on a district scale is energy efficient and rewarding. Examining the potentials of thermal energy for seasonal storage and air conditioning might be a breakthrough existing barriers. As the paper is a part of an ongoing research, the authors will continue drawing on market analysis and cost feasibility in detail to maximize the life cycle benefit and cost.

7. Acknowledgements

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