



Existing Residential Buildings Energy Retrofitting Integrating Solar Thermal Cooling: A Solution for Energy Consumption to Achieve Thermal Comfort – Case Study

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Abstract

The residential building sector has been the main focus of investments in Egypt in recent years. Such interest in constructing new residential buildings tremendously increased residential sector energy consumption. This created an imbalance with generated power growth. Such increases require interference to reduce energy consumption. This paper is focused on applying existing building energy retrofitting to decrease energy consumption. This is achieved through introducing energy-efficient cooling systems to the building and the installation of onsite renewable energy harvesting systems. This paper aims to accomplish building energy retrofitting by the following research methodology: It combines the empirical and comparative analysis research methods. The empirical method is used to analyze the current case study energy consumption due to cooling loads as well as analyzing building state post applying energy retrofitting actions. The comparative analysis method is used to compare energy consumption before and after the energy retrofitting. Research value lies in propositioning the feasibility of solving the energy crisis in existing residential buildings in addition to preserving the thermal comfort levels. The paper's result is providing a methodology for applying energy retrofitting and proving its feasibility as a proportional solution for the energy crisis.

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KeyWords: Case, Study, Solar, Solution.

DOI Number: 10.14704/nq.2022.20.6.NQ22336

NeuroQuantology2022; 20(6):3342-3357

1. Introduction

The Egyptian population now is estimated to be 102,192,247, with a population rate of 1.31% (Central Agency for Public Mobilization, 2021). The increase of the expansion rate of residential compounds and new communities, make an increase in energy consumption over the years from 2010 to 2015 by (2%). As for last year, the Residential sector consumed (41.4%), followed by the industrial sector (27.7%) and then the commercial sector (12.8%) as shown in Figure 1.

(Egyptian Electricity Holding Company, 2020).

The reasons behind residential sector energy consumption were clarified by a study that was published in 2020. The study worked on providing a breakdown of electricity usage in residential buildings. Through it was found that the occupant's consumption was mainly to satisfy indoor acclimatizing purposes, which took around 47% of the total electricity consumed, divided between 45% for cooling and 3% for heating (Nafeaa et al, 2020).

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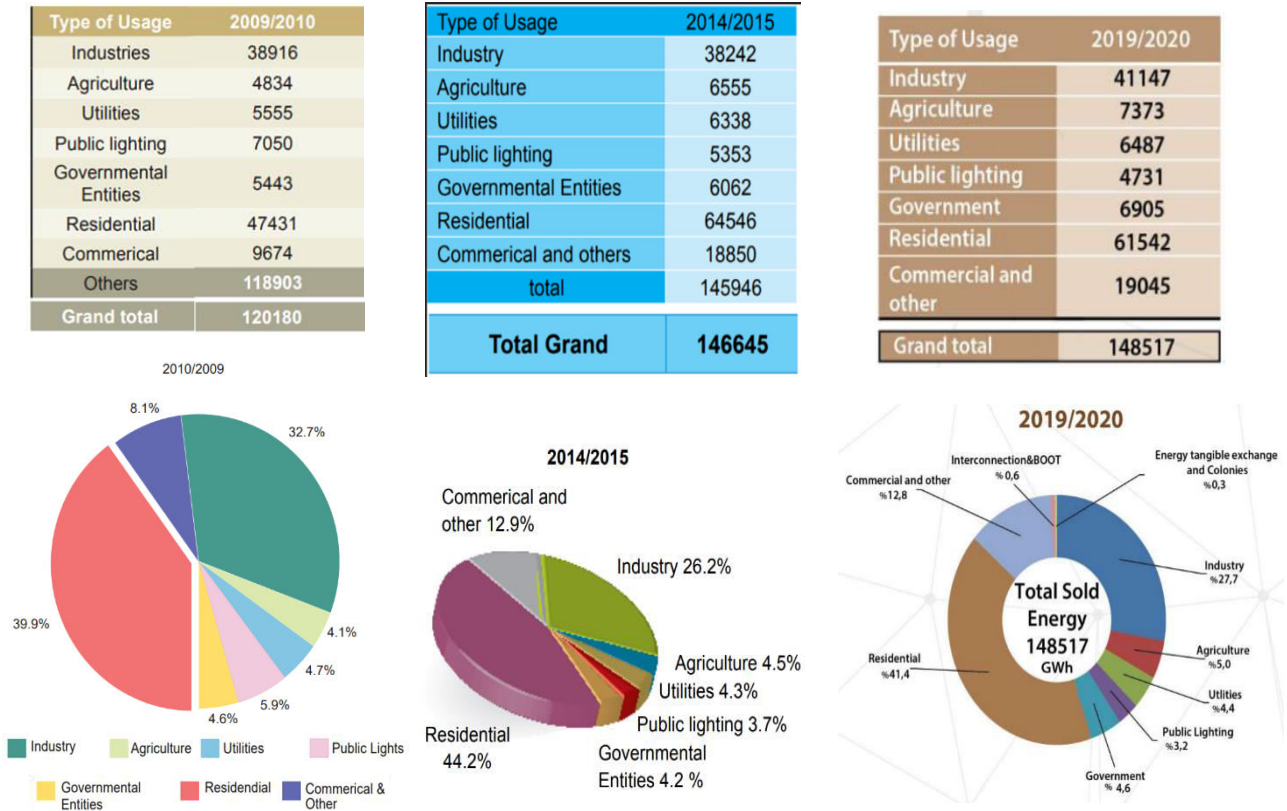


Figure 1. Electricity consumption by sector comparison over the last 10 years
 Source: (Egyptian Electricity Holding Company, 2020)

ELECTRICITY CONSUMPTION BREAKDOWN

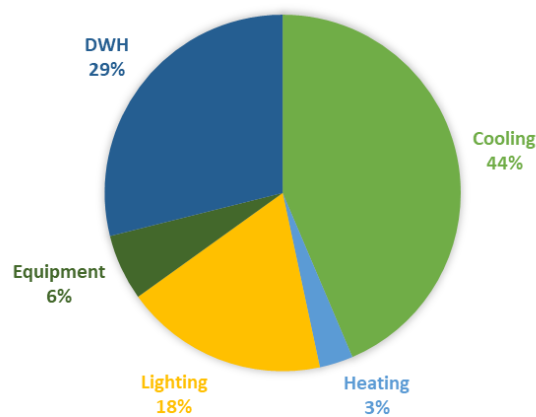


Figure 2. Electricity consumption by usage
 Source: (Nafeaa et al, 2020)



2. Literature Review

2.1. Building inefficiency

The building sector in Egypt has low indoor air quality and poor building thermal performance. This was stated based on the results of the survey (Attia et al, 2012). It showed the correlation between residential building construction qualities and occupants’ response to reach thermal comfort and the influence this correlation has on electricity consumption.

The survey clarified that residential building materials don’t have the qualities to maintain acceptable indoor thermal comfort. As building walls weren’t insulated and no shading treatment was considered. Along with openings being single glazed which allows for an increasing heat gain. The occupants reacted to compensate for this lack of thermal comfort by purchasing air conditioning units, this resulted in the installation of at least one air conditioning unit in 80% of the surveyed apartments. In return, such behavior affected peak electric loads to the point of failure and grid shutdown, as experienced earlier in Egypt.

2.2. Building Energy Retrofitting

Building energy retrofitting is a multi-objective optimization problem (Liang et al., 2018). its common objectives include cost reduction, reduced environmental impact, and improved living conditions within buildings. Depending on the

objective of an upgrade, several metrics can be used to evaluate the effectiveness of upgrades. Typical metrics include changes to internal temperature, changes to measures of thermal comfort, reduced space heating and/or cooling demand, reduced energy use, improved indoor environmental quality, and reduced carbon emissions. These performance metrics were often defined by the funding body within the literature set and have been categorized into four overarching performance drivers (Carratt et al., 2020). These are:

- i. Energy reduction: the measure of reduced energy demand. Due to the nature of the investigated retrofits, this is usually directly linked to reduced heating and/or cooling demand.
- ii. Thermal comfort and Indoor Environmental Quality (IEQ): where thermal comfort is evaluated by comparing indoor air temperature against various comfort metrics (ex. PMV).
- iii. Economic: the financial implications of retrofitting on investment returns, energy bills, and co-benefits to the economy.

To sum up, the characteristics of Energy Retrofitting are as stated:

Energy Efficiency: Energy demand should be highly reduced.

Energy requirements should be fulfilled to a very significant extent by renewable resources.

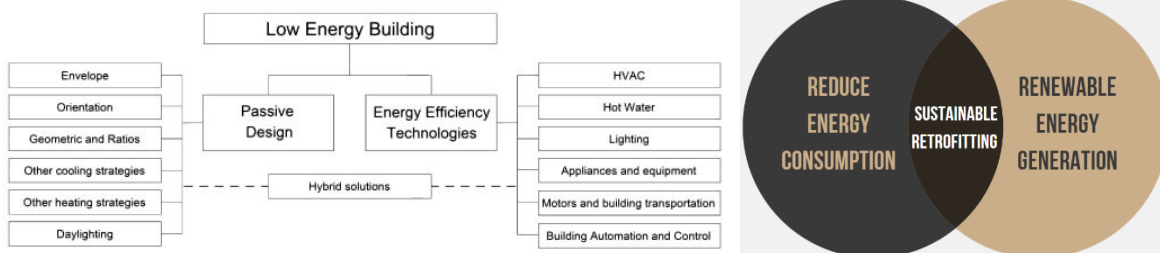


Figure 3: Aspects of reaching Energy Retrofitting
Source: (Rodriguez-Ubinas, Rodriguez, Voss, & Todorovic, 2014)

2.2.1. Energy Efficiency

Energy efficiency is a fundamental aspect of energy retrofitting, "... It implies that the energy demand for heat and electrical power is reduced, and this reduced demand is met on an annual basis from renewable energy supply". (Wang et al., 2009) Energy efficiency does not come at the expense of thermal comfort or electrical demands' fulfillment,

on the contrary, energy-efficient buildings can provide the users with their needs, but at minimum energy usage.

The energy efficiency technologies shown in figure 3 can be implemented on existing buildings, like installing an effective HVAC system and decreasing the hot water and lighting usage. These technologies are expected to decrease energy consumption to a significant extent. In the general



case, the passive applications could not be used for existing buildings. (Rodriguez-Ubinas, Rodriguez, Voss, & Todorovic, 2014). HVAC is the only alternative that will be studied as a possible solution of energy efficiency, as it was elaborated previously how residential building poor thermal performance resulted in the high dependency on air conditioning system which in return highly affected energy consumptions.

A. Solar Cooling

The term 'solar cooling' refers to devices and processes that use solar energy for cooling. Solar cooling systems have the advantage of using predominantly non-toxic and environmentally sound working fluids such as water or salt solution and can be used as standalone systems. They are, in

many cases, able to simultaneously generate refrigeration and save conventional energy (Tsoutsos et al, 2004).

The solar cooling system is generally comprised of three sub-categories as shown in figure 4 (Ayman J. Alazazmeh, 2015), Only Solar thermal cooling will be targeted in this paper:

1. Solar energy conversion system, Solar Collectors (SCs) or Photovoltaics Panels (PVs) and their system of operation.
2. Refrigeration system, different types of processes that works by converting harvested thermal energy in a form of heated liquid to cooling power.
3. Cooling loads, the desired levels of energy that need to be compensated to reach the operative temperature of the targeted space for cooling.

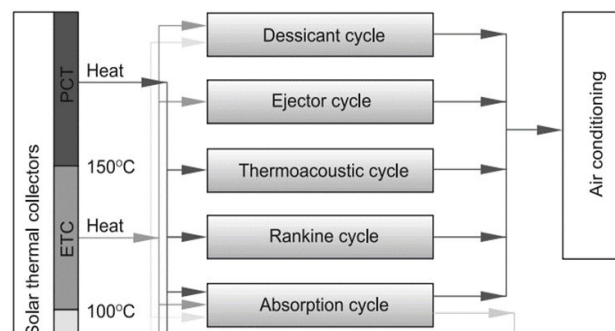


Figure 4: Solar thermal cooling technologies
Source: (Ayman J. Alazazmeh, 2015)

Solar Thermal Absorption Refrigeration System

The cycle will be based on (Alsaqoor et al, 2014) studies in which they assisted the performance of the absorption refrigeration cycle under variable power sources namely electric, conventional fuel, and renewable energy sources. the ammonia-water absorption cycle was used in this work. the coefficient of performance and efficiency of the plant was measured and then compared. The results showed that when the cycle was driven by the solar thermal energy the coefficient of performance reached 0.801 along the test time. They concluded that Solar energy can be used efficiently and replaced the conventional power

sources to drive the absorption refrigeration unit. typical prices for a solar cooling system are around \$3000 per kW of cooling capacity and it has a lifetime of 15–20 years (Jakob, 2016).

2.2.2. Renewable Energy Generation

Based on the used system, The chosen renewable energy system that will be used is the solar thermal energy system. The flat Solar collector used for the system is provided by Apricus Co., it has the following properties shown in figure 5, peak power output (2114 W) and gross area (2.99m²) are the main inputs for the upcoming system calculations.



Physical Specifications

Dimensions (LxWxH): 2444 x 1223 x 80 mm
 96.2" x 48.1" x 3.15"
 Aperture Area: 2.8 m² / 30.14 ft²
 Gross Area: 2.99 m² / 32.2 ft²
 Gross Dry Weight: 46 kg / 101.2 lbs
 Fluid Capacity: 1.8 L / 60.9 floz
 Max Pressure: 800 kPa / 116 psi

Performance Data

Peak Power Output: 2114 W / 7,213 Btuh *
 Eta0: 0.755 *
 a₁ (W/m²K): 3.738 *
 a₂ (W/m²K²): 0.007 *
 Nominal Flow Rate: 2 L/min / 0.5 Gpm
 Max Flow Rate: 15 L/min / 4 Gpm

* Data from TUV test report, 1000W/m², based on aperture area.

Figure 5. Solar collectors’ data sheet
 Source: (Apricus, 2021)

Table 1. Fixation Angles and corresponding monthly solar gains

Month	Optimum tilt deg	Radiation at opt. tilt Wh/m ² /day	Seasonally opt. tilt deg	Radiation at seasonally opt. tilt Wh/m ² /day	Two times tilt per year deg	Radiation at two times tilt Wh/m ² /day	Fixed tilt at 30° deg	Radiation at fixed tilt at 30° Wh/m ² /day
Jan.	55	5570	55	5570	48	5540	30	5110
Feb.	47	5940	32	5770	48	5940	30	5720
March	34	7120	32	7110	10	6620	30	7100
Apr.	18	6960	32	6810	10	6910	30	6850
May	5	7540	0	7520	10	7520	30	7000
Jun.	0	8120	0	8120	10	7980	30	7150
Jul.	1	7930	0	7920	10	7850	30	7170
Aug.	13	7510	28	7300	10	7500	30	7250
Sept.	29	7080	28	7080	48	6740	30	7080
Oct.	43	6790	28	6600	48	6760	30	6640
Nov.	53	6040	55	6030	48	6020	30	5620
Dec.	57	5520	55	5520	48	5450	30	4980

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Fixation Angle

Experiments and computations proved that four options can be considered as shown in table 1 and their efficiency is shown in table 2. The best tilt angles for receiving the highest solar radiation vary monthly between 0° to 55°. (Hegazy, 2019)

The combination between the energy-efficient

HVAC system and solar thermal energy generation provides an adequate sustainable retrofitting methodology to be used as a potential solution for high energy consumption. Nevertheless, the system validation will be measured based on thermal comfort parameters and cost-efficiency.



Table 2. Tilt Angles and annual solar gains
Source: (Hegazy, 2019)

Optimum tilt	Yearly average radiation Wh/m ² /day	gain over horizontal	Radiation gain over fixed tilt
Monthly	6834	16 %	5.5 %
Seasonally	6779	15 %	4.6 %
Two times	6736	14 %	4 %
Fixed, 30°	6480	10 %	
Horizontal	5900		

2.3. Thermal Comfort

A clear definition of thermal comfort is: “It represents the subjective state of mind satisfaction with the thermal environment and is assessed by subjective evaluation (ASHRAE, 2017). So, comfort in the context of indoor climate is the degree of satisfaction experienced by the users which they would like to live or work with”.

To summarize the thermal comfort range in Egypt, the Housing and Building National Research Center (HBRC) had defined the acceptable ranges for Cairo as follows:

Indoor air temperature between 24°C and 29°C

Relative humidity between 30% and 50%

Air velocity 0.5 to 1.5 m/s

Solar exposure is desirable when the temperature is less than 23°C

Cooling is needed when the temperature is more than 31°C.

Predicted mean values is limited to the following, - 0.7 > PMV < 0.7 (HBRC, 2005)

3. Methods

The specific target of this research is to achieve thermal comfort inside residential buildings with the most economical solution on both the energy and financial levels. The anticipated methodology, as seen in figure 6, follows the energy retrofitting approach by applying research methods of:

Empirical Method: it is used on the current residential building state before any interference and on the same building upon the application of energy retrofitting measures as a solution. This method is performed by the usage of energy simulation programs. Firstly, to investigate the current case study state DesignBuilder is used to obtain energy consumed for cooling purposes, current thermal comfort levels, and the cooling loads required to achieve thermal comfort. Secondly, retrofitting actions are applied which involves the installation of a solar thermal cooling system as well as an onsite solar thermal energy harvesting system. The effect energy retrofitting has on energy consumption levels to achieve thermal comfort is calculated to analyze solution feasibility. therefore, the result of this method is to obtain energy consumption levels in the two states. Comparative analysis method: Previous method results are used in the following manner. For each state of the case study, a financial analysis is produced. It compares the two states financially based on system initial cost, monthly running cost, payback time, energy savings over system lifetime, and end-user share of costs. All financial calculation is based on the most recent Egyptian electricity tariffs. The comparison results indicate the feasibility and potential of the energy retrofitting.

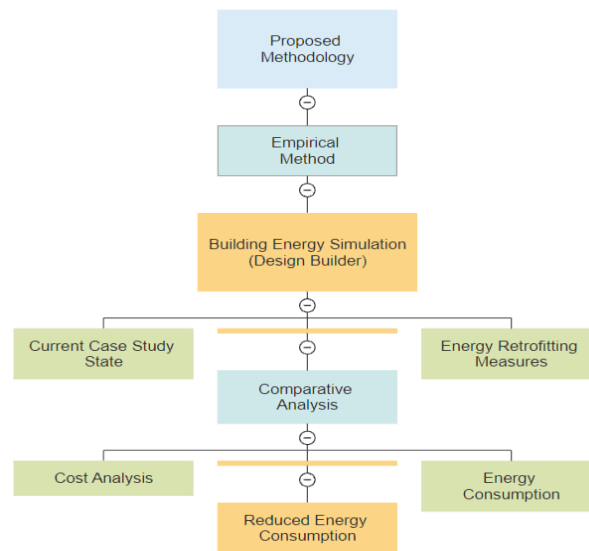


Figure 6. Proposed Methodology as a solution for energy and thermal comfort issues

4. Case Study

The proposed retrofit is applied to a case study of an existing residential building in Cairo to test its actual feasibility. The detailed step by step methodology is performed as follows:

4.1. Reference Building Selection

The case study was chosen in Cairo according to the Census data. It stated that Egypt has a total of 4,075,400 residential buildings. Cairo has the

highest number of 598,311 buildings (14.68%). 88% of air-conditioned apartments are found in the high-rise residential buildings in Cairo. The size of the apartments varies substantially but they are classified according to the census into classes from A to D (CAPMAS, 2017):

- A: 7% have gross areas greater than 130 m².
- B: 47% have gross areas between 110 and 130 m².
- C: 23% have areas between 90 and 110 m².
- D: 11% have areas between 60 and 90 m².

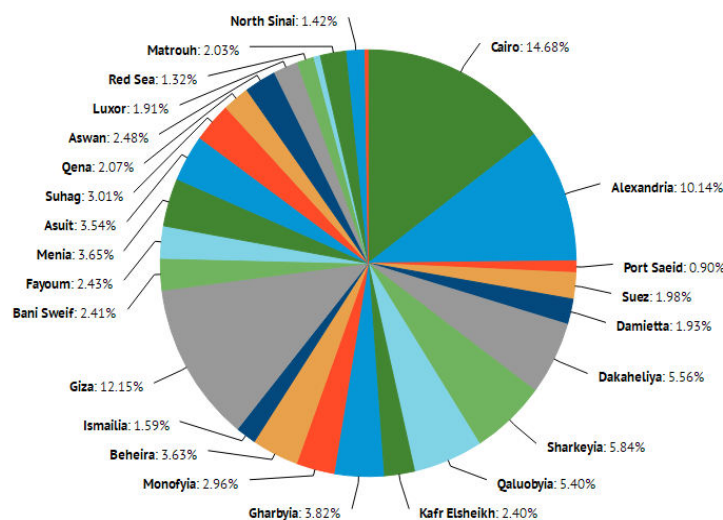


Figure 7. Total Regular Buildings for Housing Purposes - Urban
 Source: CAPMAS. (2017). The final results of population and housing census 2017. Cairo: CentralAgency for Public Mobilization and Statistics.



Governorates	Cairo	Alexandria	Port Saued	Suez	Damietta	Dakaheliya	Sharkeyia	Qualuobyia	Kafr Elsheikh
Units	598,311	413,420	36,603	80,713	78,468	226,411	238,092	220,045	97,761
Governorates	Monofyia	Behira	Ismailia	Giza	Fayoum	New Vally	Matrouh	North Sinai	Bani Sweif
Units	120,533	147,876	64,754	494,996	99,078	20,746	82,635	57,846	98,102
Governorates	Asuit	Suhag	Qena	Luxor	Aswan	Red Sea	South Sinai	Menia	Gharbuya
Units	144,353	122,770	84,552	78,010	101,235	53,720	10,154	148,632	155,583

Based on this classification, the majority of air-conditioned residential apartments are in class B. Therefore, the case study was aimed at screening and selecting apartments that fall in class B with high penetration values of air-conditioning units.

4.2. Building data

The case study building is a 6-story residential building with two apartments per floor each (12 Apartments) of an approximate area of 122 m² and the total surface area of the building is 275 m². The

building has one staircase acting as the core vertical circulation. Each apartment has a perimeter of 60.35m and a ceiling internal height of 2.8 m. It is rectangular and consists of three bedrooms, a living room, and Kitchen. The number of occupants is an average of 5 persons. The typical floor plan and 3d model for the prototype are as seen in figures 8a and 8b respectively. The building is located in an average residential community in Al Mohandessin area with orientation to the North.

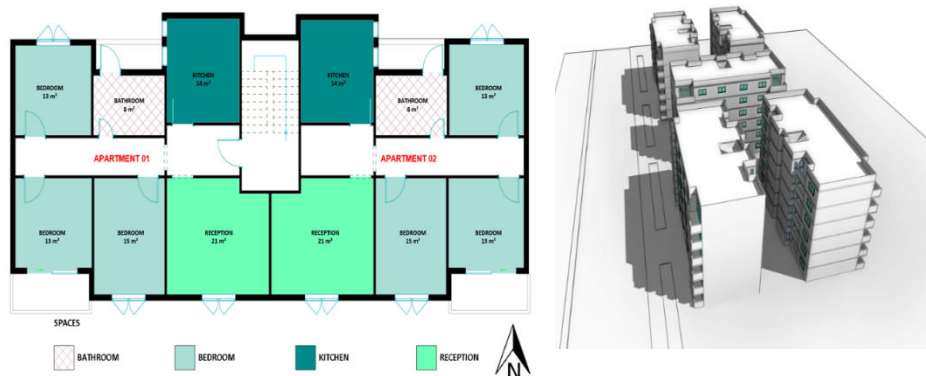


Figure8. Typology 1 Apartments architectural design
a. Architectural Plan, b. Buildings Layout

4.2.1. Material Specifications

The construction consists of typical brick walls (External walls), it consists of red brickwork and plaster. The various material of the building envelope layers the thicknesses, and energy performance data are listed in Table 3. The commonly used Clear 6.4 mm single glass with a U-

Value of 5.76 was employed in the simulations, as mentioned and specified in the Egyptian Residential Energy Code (EREC). The thermal properties for the construction materials were obtained from EREC (Housing and Building National Research Center, 2006).



Table 3: Building's core materials Thermal Properties
Source: (Housing and Building National Research Center, 2006)

No.	Location	Layering	Thickness	U-Value	R-Value
A	Internal Wall	125 mm Egyptian red Brick	125mm	1.9	0.4
B	External Wall	250 mm Egyptian red Brick	250mm	2.5	0.5
C	Typical Floor Layers	0.12m reinforced concrete, 0.05 m sand, 0.02 m cement, mortar, 0.02m ceramic (0.15 m reinforced concrete, 0.02 m	200mm	1.58	0.63
D	Roof	betomine damp insulation, 0.05 m sand, 0.02 m cement mortar, and 0.02 m concrete tiles	270mm	1.39	0.72

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4.3. Simulation

For the retrofit actions to be verified, energy simulation needs to be performed. Using DesignBuilder software the thermal comfort and cooling loads of the existing building with its current situation are done. The retrofitting actions are then simulated to be able to measure the difference in electricity consumption between the two cases.

Thermal Comfort has to be highlighted because it will be compared to the simulated case to show the effectiveness of the proposed retrofit actions. It was found that the building performed extremely poorly during 6 months and occupants suffer from thermal comfort inefficiency. This was reflected According to the PMV index and the corresponding thermal sensation as shown in figure 9, on Residents thermally indoor conditions perceptiveness to vary mostly between “Warm” and “Hot”.

4.3.1. Current Thermal Comfort and Electricity Consumption Simulation

Table 4: Thermal Sensations
Source: (Iziomon et al., 1999)

PMV	PET [°C]	Thermal perception	Grade of physiological stress
< -3.5	< 4	Very cold	Extreme cold stress
-3.5 - -2.5	4 - 8	Cold	Strong cold stress
-2.5 - -1.5	8 - 13	Cool	Moderate cold stress
-1.5 - -0.5	13 - 18	Slightly cool	Slight cold stress
-0.5 - 0.5	18 - 23	Comfortable	No thermal stress
0.5 - 1.5	23 - 29	Slightly warm	Slight heat stress
1.5 - 2.5	29 - 35	Warm	Moderate heat stress
2.5 - 3.5	35 - 41	Hot	Strong heat stress
> 3.5	> 41	Very hot	Extreme heat stress



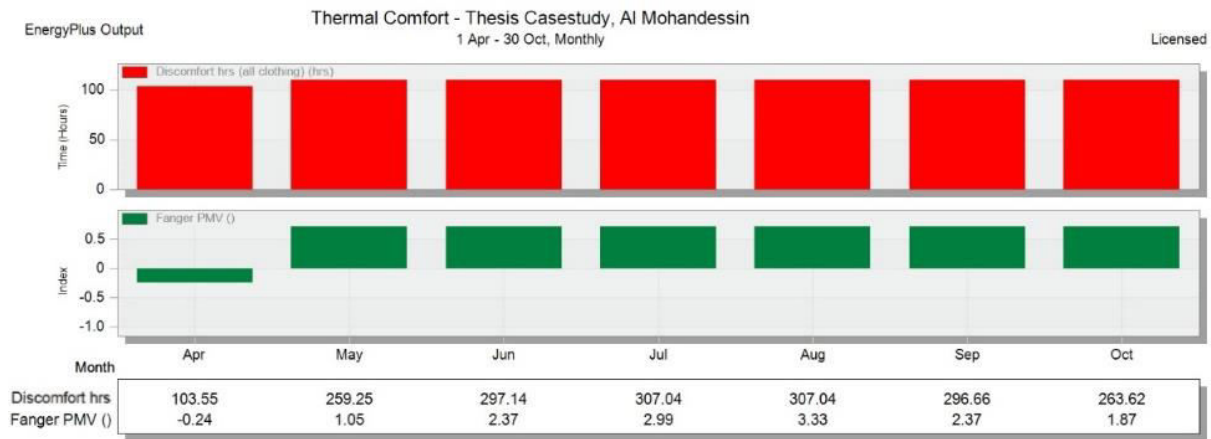


Figure 9: Current Residential Building Thermal Comfort Stats

The previous thermal comfort results are 935, 1173, 1236, 900, 616 kWh during months compensated by users by depending on from May to October respectively as shown in conventional cooling systems (Split units). Such dependence resulted in the consumption of 592,

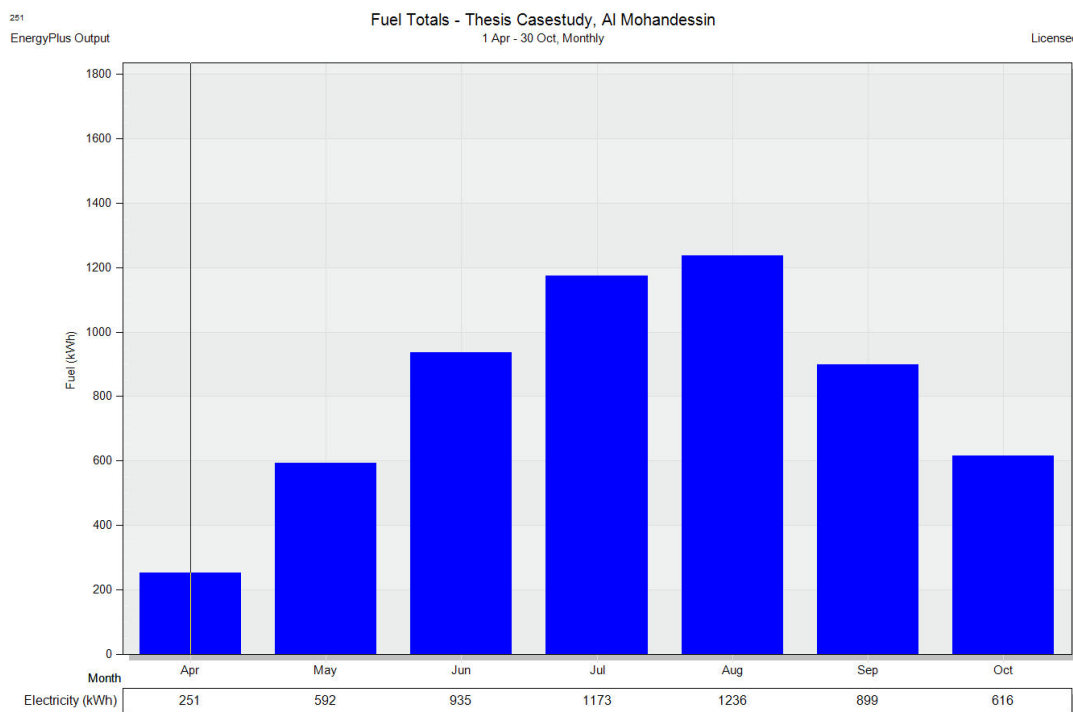


Figure 10. Electricity Consumption during month of low thermal comfort

4.3.2. Cooling loads to reach Thermal Comfort

The following figure 11 shows the required levels of thermal comfort according to previously stated parameters. To achieve such values, cooling loads were simulated using DesignBuilder to use it invalidating retrofitting actions. The peak cooling

load was found to be 9.6 kW (Design capacity = 11 kW) to reflect the following PMV values. This will be the guideline to compare sustainable retrofitting methodology and current case (Conventional HVAC) energy consumption and their reflection finally.



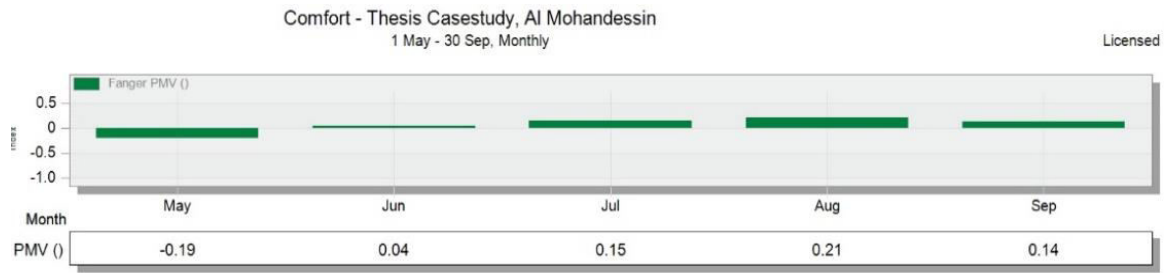


Figure. 11 Targeted thermal comfort Levels according to HBRC requirements

4.4. Cost Analysis

Through the following section, the amount of energy needed to be consumed will be reviewed for both Solar Cooling and AC units to compare their financial feasibility.

For the financial analysis, the cost of the annual energy consumption per flat was calculated using the electricity tariff set by the Egyptian Ministry of Electricity and Energy for the residential sector. The different categories and prices are shown in Table 6. The simulation results showed that average energy use per apartment for the case study during months of poor thermal comfort follows the > 1000 usage category for 1.40

EGP / kWh.

4.4.1. Current Air Conditioning Systems

Obtaining energy consumption will be presumed by the usage of a typical AC unit available in the Egyptian Market. To cover this cooling demand, an AC unit by Unionair (Artify Model – ART 010) (UnionAir Group , 2021) which were used with a cooling power of 2.64 kW and electricity consumption of 0.93 kW for cooling. These specs inform that to meet the cooling demand Number of units will be determined as follows,

$$\text{No. of Units} = \text{Cooling Demand} / \text{AC Cooling Power} = 11 / 2.64 = 4 \text{ units}$$

Table 5 Unionair Artify model Specs
Source: (UnionAir Group , 2021)

Category (kWh)	Price (EGP)
< 50	0.38
51 - 100	0.48
101 - 200	0.65
201 - 350	0.96
351 - 650	1.18
> 1000	1.4



Table 6 Egypt Electricity Tariffs
Source: (Egyptian Electricity Holding Company, 2020)

Indoor Unit		ART I 010
Outdoor Unit		ART O 010
Nominal Cooling Capacity	KW - Btu/hr	2.64 - 9000
Cooling Power Consumption	W	930

Their cooling power consumption is calculated as follows,
 Cooling Power Consumption (Apartment / Year) = AC Cooling Electricity Consumption X No. of ACs X Operation Hours X Days of a month X Operation Months
 = 0.93 X 4 X 12 X 30 X 6 = 8035 kW.h / Year / Apartment
 = 8035 kW.h X 12 = 96,422 kW.h / Year / Building
 To calculate electricity consumption cost both yearly and in 20 years,
 Yearly Electricity Consumption Cost =

Cooling Power Consumption X Electricity Tariff
 = 96,422 X 1.40 = 134,990 EGP / Building / Year = 2,700,815 EGP / Building / 20 Years
 For the total cost, system cost (6000 EGP per AC Unit) and lifetime (20 Year) will be included,
 Yearly System Cost = (No. of Units X Unit Price) / Lifetime
 = 24,000 / 20 = 1200 EGP / Year = 100 EGP / Month
 Yearly Total Cost = 134,990 + 1200 = 136,190 EGP / Building / Year
 = 2,723,800 EGP / Building / 20 Years

Table 7: Conventional Air Conditioning System Calculations

Parameter	Value	Unit	Comments
Apartment Peak Cooling Load	11	kW	
Daily hours of Operation	12	Hour	
Months of Operation	6	Month	
AC Cooling Power	2.64	kW	
AC Electricity Consumption	0.93	kW	
No. of AC units	4	unit	= Peak Cooling load / Ac Cooling Power
Power consumption for unit/year	8035	kW.h / Year / Unit	= AC Cooling Electricity Consumption X No. of ACs X Operation Hours X Days of a month X Months of Operation
Power consumption for 12 units/year	96,422	kW.h / Year / Building	
System Cost	24,000	EGP	
Lifetime	20	Year	
Total Cost / year	136,191	EGP/Year/Building	
Total Cost / 20 year	2,723,800	EGP	

4.4.2. HVAC Retrofitting

Retrofitting action will involve the installation of solar collectors along with a solar absorption cooling system. Firstly, the energy consumed by the cooling system, for the whole building, will be obtained by using the following Equation (Ibrahim

Dincer, 2021);
 COP = Q Cooling / Energy Input
 COP: Absorption Chiller Performance Coefficient = 0.8
 Q Cooling: Chiller Cooling Capacity (kW) = 11 kW
 Energy Input: Required Energy for System



Operation (kW)

This resulted in obtaining the energy input of 13.75 per Apartment accounting for 165 kW energy consumed by the whole building (12 Apartments).

The energy produced by SCs is obtained through the following:

No. of Panels = Total Energy Consumed / Power Output per Panel

= 165 / 2.114 = 79 Panel

Actual Energy Output = No. of Panels X Power Output per Panel

= 79 X 2.114 = 167 kW

The required area for Flat Plate Solar Collectors Fixation is calculated based on:

Total Area for Panels = No. of Panels X Gross area of a single Panel

= 79 X 3 m2 = 237 m2

for SCs installation roof area will be used which is accounting for 229m2

% Sufficiency = Available area / Total Area of Panels

= 229 m2 / 237 m2 = 96.62%

Sufficiency indicates that 96.6% of the Solar cooling system energy needs will be compensated solely by depending on solar energy which means the building cooling loads.

Next is to calculate the total energy consumed throughout the year to obtain energy cost,

Total Energy per Year =

per month X No. of Months X Days in a month X Hours of Operation

= 165 X 6 X 30 X 12 = 365,400 kW.h

Energy Cost per year (Solar Cooling system)

= Total Energy per Year X Cost per kWh

= 365,400 X 1.40 = 498,960 EGP/Year

This result indicates the energy cost in case it was supplied by the national grid electricity. This value is then used to determine how much energy will be compensated if electricity were to be replaced by Solar energy based on the sufficiency calculated earlier, As follows:

Total Saved Per Year = %Sufficiency X Energy Cost per year

= 96.6% X 498,960 = 482,180 EGP / Year

For the saved costs throughout the system lifetime, Lifetime Savings = Total Saved per year X System Lifetime

= 482,180 X 20 years = 9,643,600 EGP

Net Saved = Lifetime Savings – System Cost

= 9,643,600 - 520,000 = 9,123,600 EGP / 20 Years / Building

With such savings, the system can pay back its cost in 1.1 years through,

Payback Period = System Cost / Saved Per Year = 520,000 / 498,960 = 1.1 Years

Parameter	Value	Unit	Comment
working hours per day	12	Hour	
working months per year	6	Month	
Total energy per year	356,400	kW.h	= Peak Energy Consumed * Months of Operation * Days in a month * Hours of Operation
Cost per kWh	1.4	EGP / kWh	
Total cost per year	498960	EGP	= Total Energy * Cost per kWh
Total saved per year	482117	EGP	= %Sufficiency X Energy Cost per year
System cost	520,000	EGP	
Lifetime	20	Year	
Total saved (lifetime)	9,382,35	EGP	= Total Saved * Lifetime (20 year)
Net saved (lifetime)	8,862,350	EGP	= Total Saved – System Cost

Table 8: Solar thermal cooling System Calculations

4.4.3. Single Apartment Shares

Solar cooling system costs and savings targeted for a single apartment will be reviewed in comparison

to a conventional air conditioning system to clarify cost efficiency. To start, each apartment share of costs and savings shall be calculated.



Solar Thermal Cooling system

Table 9: Solar Cooling System Financial review per Apartment

Parameter	Value	Unit
Cost Per Unit Per Month	6930	EGP/Month/Unit
Saved per unit per month	6700	EGP/Month/Unit
System cost	520,000	EGP
Life time	240	Month
System cost per month	2160	EGP/Month/Building
System cost per unit per month	180	EGP/Month/Unit
Total Cost Per Unit Per Month	400	EGP/Month/Unit
Total saving per unit (lifetime)	781,860	EGP/20 Year/Unit
Total system cost per unit (20Year - lifetime)	43,300	EGP/20 Year/Unit
Total Saving Lifetime	9,382,350	EGP/20 Year/Building

Energy Consumption Cost (Apartment / Month)
 = Total cost per Month /Apartments = (498,960/6)
 / 12 = 6930 EGP / Month / Apartment
 Energy Consumption Cost Saved (Apartment /
 Month)
 = Total Cost per Month X %Sufficiency = 6930 X
 96.6% = 6700 EGP / Month / Apartment
 `System Cost per Apartment / Month
 = System Cost / Lifetime / No. of Apartments =

(520,000 / 240) / 12 = 180 EGP / Apartment
 Monthly Cost for Each Apartment = 6930 – 6700 +
 180 = 400 EGP / Month / Apartment
 This result, 400 Egp, is accounted for an average
 added to the electricity bill fees, including system
 cost and cooling energy consumed, required from
 each apartment through months with cooling
 demands.

4.3.4. Conventional air conditioning system

Table 10: Conventional Cooling System Financial review per Apartment

Parameter	Value	Unit
System Cost / Month	100	EGP / Month
Cost / Year / 12 Unit	136,190	EGP/Year/Building
Total Cost/Unit/Year	11,350	EGP/Year/Unit
Total Cost/Unit/Month	1900	EGP/Month/Unit

Energy Consumption Cost (Apartment) = Total cost
 per Month / No. of Apartments
 = (136,200 / 6) / 12 = 1900 EGP / Month /
 Apartment

The resulted cost, 1900 Egp, reflects the average
 added to the electricity bill fees needed to be paid
 by each apartment through months with cooling
 demands.



5. Results and Discussion

Table 11: Financial Comparison between Solar & Conventional cooling systems

Parameter	Solar Thermal Cooling System	Conventional AC System (Split Units)	Unit
Initial Cost	520,000	24,000	EGP
Total Cost / Month / Unit	400	1900	EGP/Month/Apartment
Total Cost / Year / Unit	2400	11,400	EGP/Year /Apartment
Total Cost / Year / 12 Units	28,800	136,800	EGP/Year /Building
Total Cost / 20 Year / Unit	48,000	228,000	EGP/20Year /Apartment
Total Cost / 20 Year / 12 Units	576,000	2,736,000	EGP/20Year / Building
Total Saved / 20 Year / Unit	781,860	-	EGP/20Year /Apartment
Total Saved / 20 Year / Building	9,382,350	-	EGP/20Year /12 Apartment

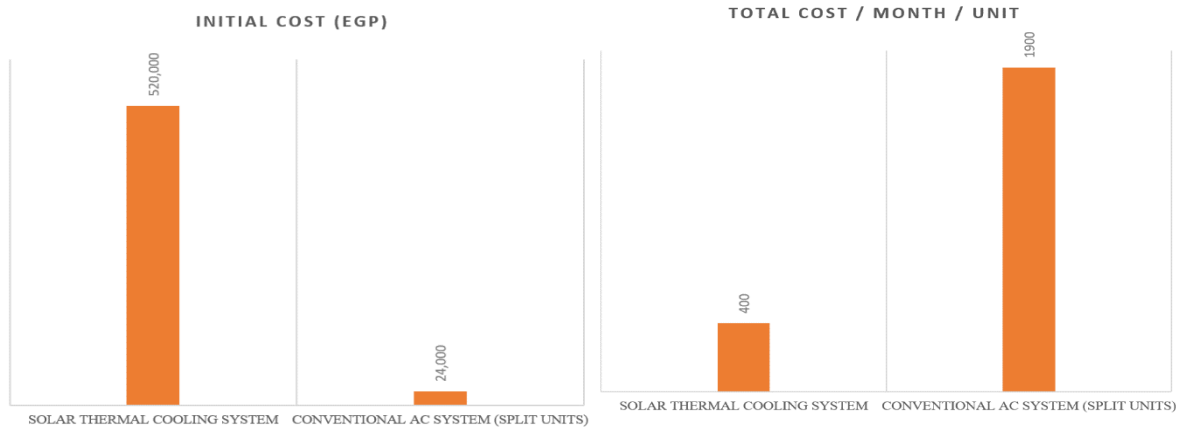


Figure 12: Initial Cost & total Cost for Solar thermal cooling vs Conventional AC Systems

For a Conventional Cooling System (AC Split Units), It is estimated that the 6 months of high levels of indoor temperatures will impact the electricity bill by 1900 EGP for each month. This price includes the system initial cost divided by 240 monthly installments, system lifetime (20 Years), which is 100 EGP/Month. The system has a low initial cost of 24,000 EGP for 4 AC units to condition a living room and 3 bedrooms. The system electricity consumption costs yearly 11,400 EGP/Year/apartment. when the system lifetime is due, the end-user will be charged 228,000 EGP/20Year.

For the proposed Solar Absorption Cooling System, this system will completely compensate the dependence on electricity to be replaced with solar thermal energy. it has an outstanding coverage percentage of 96.6%. this means that the system will efficiently substitute the necessity for electricity in cooling needs for residential buildings. For such efficiency to be achieved, the building roof area (244m²) was used for the system equipment and solar collectors' installment. The system is estimated to lower electricity bills fees as low as 400 EGP/Month over 240 monthswchich is the system lifespan. this fee



includes the system cost of a monthly payment of 180 EGP. The system initial cost is quite high recording 520,000 EGP for the entire building and 43,300 EGP per apartment. By the end of the system lifespan, the end-user would have paid 2400 EGP/Year and 48,000 EGP/20Year which is a great saving in comparison to the conventional system.

6. Conclusion

Existing residential buildings in Egypt suffer from poor building thermal performance levels which increases the energy consumed to reach the thermal comfort inside the building. A possible solution for this problem is to put existing buildings through energy retrofitting to convert them to Energy-efficient buildings. The study presented a retrofitting proposal and implemented it on an existing residential building in the Egyptian context in Cairo. The study was applied through the Empirical and comparative analysis approaches. Through simulation, the current state of the existing building was evaluated. the simulation was used again after applying the retrofitting measures. A comparative evaluation was done between the two states based on the financial and thermal comfort scopes. The results of the study revealed that an existing residential building can be converted to an energy-efficient building using the proposed methodology. The cost analysis implemented in the study reveals the exact costs of the retrofit actions using solar cooling systems. it was found to be affordable due to a payback period of 1.1 years. Low fees of 400 EGP were required from the end-user for the solar thermal cooling system cost and usage during the 6 months of usage only. Such results managed to achieve an astonishing 9,382,350 EGP saving over 20 years of lifetime. In comparison, a conventional cooling system costs 11,400 yearly and 228,000 over 20 years.

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