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Electrical Energy Consumption Pre and Post Energy Conservation Measures: A Case Study of One-story House in Dhahran, Saudi Arabia

Ibraheem A. Al-Mofeez
Associate Professor, College of Architecture & Planning, King Faisal University
ibraheem@kfu.edu.sa
Mobile: 96650 382-5185

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Abstract. This paper discusses the energy savings from retrofitting a one-story house located in Dhahran, Saudi Arabia. Actual monthly bills were recorded 72 months before and 72 months after retrofitting. The building description and the users' profiles are different before and after the study as indicated by non-A/C monthly electric consumption 1022 kwh and 1772 kwh respectively. In order to account for those differences, electrical consumption attributed by A/C in summer was isolated and compared. The study followed the International Performance Measurement & Verification Protocol (IPMVP) in assessing the impact of energy conservation measures on building energy consumption. The study showed significant savings in air conditioning consumption due to building envelope 40%, and the peak monthly load was reduced by 34% after the retrofitting. The same conclusion can be drawn on the peak hourly demand due to contribution from building envelope.

Introduction

The electrical energy supply did not meet the increasing demand from new building construction and the changing life style of the public in Saudi Arabia [1]. This forced the government to curb the increasing demands, to gradually lift the subsidies to electrical companies, increase the rate per kwh of monthly consumption, and increase the initial cost of the connection to the power gridline.

The result is a compromise rate increase designed not to affect low-income families, yet rationalizes electrical energy consumption; the rate schedule calls for low rate for the first 2000 kwh (SR 0.05) and increases incrementally every 1000 kw thereafter up to (SR 0.26) after the tenth thousand as shown in Table 1. This measure is taken in conjunction with mandatory use of thermal insulation in new buildings.

Table 1. Electric energy cost [7]

kwh/month	0- 2000	2001- 4000	4001- 6000	1	1- 0	7001- 8000	8001- 9000	9001- 10000	10000 and +
SR/kwh	0.05	0.1	0.12		5	0.2	0.22	0.24	0.26

Retrofitting buildings, especially residential buildings, with thermal insulation and weather stripping can reduce electrical energy consumption and improve thermal comfort [1]. The economic benefits of retrofitting are attractive on national and individual levels. Previous studies indicated simple payback period of less than seven years [2-4]. On national levels, retrofitting can save capital investment on a new power generating plant and increase efficiency in plant operation [2]. Savings in peak electrical demands from retrofitting old buildings can offset the annual growth in peak demand periods that have to be met by the electric company [5].

Most of the theoretical and simulation studies show the benefits of retrofitting buildings with thermal insulation [2]. People become skeptical when asked about retrofitting for energy conservation and difficult to convince. They need a working example they can examine and to actually see the benefits of retrofitting.

Residential buildings are skin-load dominated (i.e. opaque envelope contributes between 30 to 45% to the cooling load). The contributions of the envelope increase with severe climates [3, 6] as shown in Table 2 and Fig. 1.

Table 2. Annual cooling load of various components of a two-story house in Saudi Arabia [2]

Component	**Annual cooling load** **%**
Infiltration/ventilation	24
Walls	23
Roof	11
Glass (conduction)	6
Glass (solar radiation)	13
Internal load	23
Total	**100**

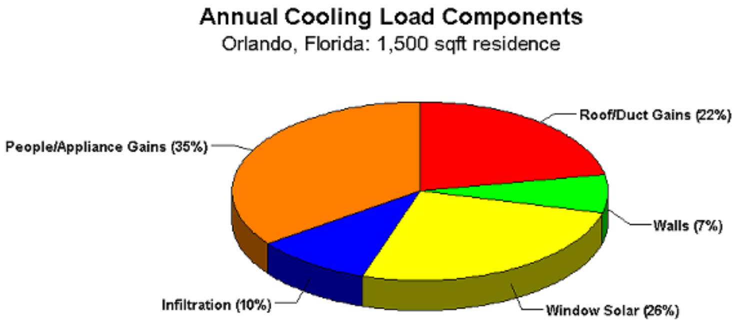
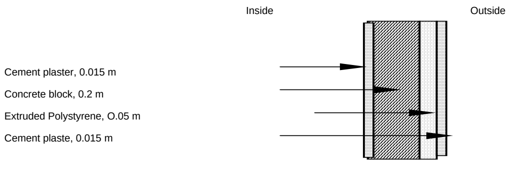


Fig. 1. Annual cooling load components [9].

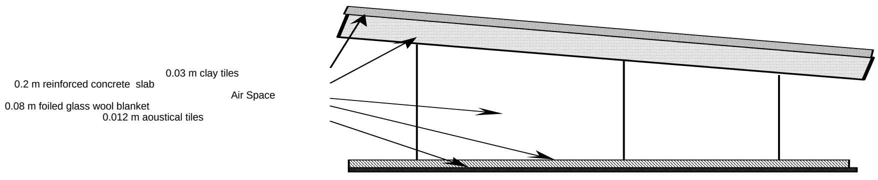
Figure 1 shows that roofs, walls and infiltration account for 39% of the annual cooling load in central Florida where the design Dry Bulb (DB) temperature is 34°C. One may extrapolate that the percentage will be greater in Dhahran where design DB temperature is 42°C [8]. Severe weather conditions can increase the contribution of the envelope to 77% of the total cooling load [2].

The Case Study: The House Description

The house is a one-story detached single-family unit with a built area of 318.8 sq meters. It is located in Dhahran, Saudi Arabia (26.27 N, 50.15 E) 17 meters above sea level. The Dhahran area is characterized by its severe climate. It is hot-arid starting April through June and hot-humid in July through October. The 0.4 percentile is 44°C and the mean wet bulb temperature is 21.8°C [10]. The building is surrounded by two one-story houses on the west and north sides, a two-story house on the south side and a 20-meter street on the east side. The house is built with concrete blocks as in-fill and a reinforced concrete roof and skeleton. The roof is pitched along the east-west axis with a 20% slope and is covered with burnt clay roofing tiles. Glazing areas are evenly distributed on all sides. The total glazed area is 11% of the floor area. (see Figs. 2, 3 and 4).



Wall Insulation



Roof-ceiling insulation

Fig. 2. Walls and roof ceiling after applying thermal insulation.

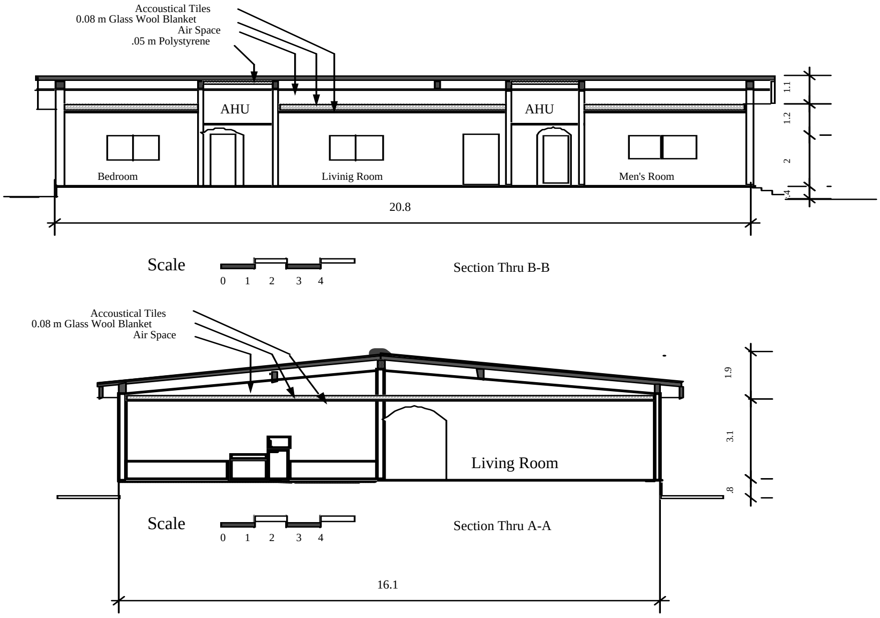


Fig. 3. Sections of the one-story house.

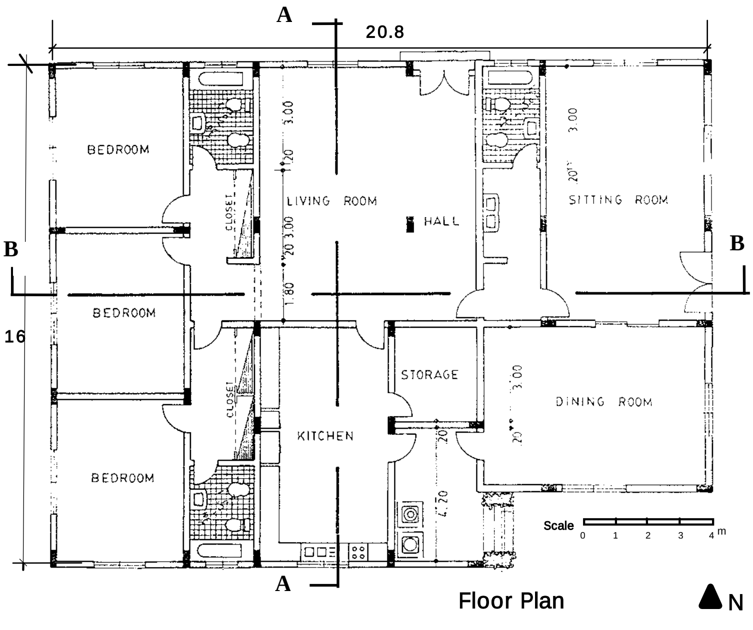


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Fig. 4. Floor plan of the one-story house.

During the course of the study, the house was occupied by two families with significant differences in user’s profiles in terms of household size, appliances, etc. Internal heat gain attributes are listed in Tables 3 and 4.

Table 3. Building physical and thermal characteristics

Attributes	Units	Before	After	Remarks	
Built Area	Sq. m	318.8	318.8	includes driver.s room	
Glazed Area	Sq. m	34.72	34.72	Gray tinted alumium frame	
Total Door Area	Sq. m	10.8	10.8		
Total Wall Area	Sq. m	289.6	289.6	Gross area	
Insulated Wall Area	Sq. m	0	191	East wall is not insulated	
Insulated Ceiling Area	Sq. m	0	318.8		
Solar Heat Gains Coeff.	%	80	80		
Infiltration	ACH	2	0.5	Estimated by the author	
Overall Wall U-Value	w/m.K	2.93	1.6		
Overall Roof U-value	w/m.K	2.9	0.92		
Fresh Air-ntake	%	20	5	Estimated by the author	
Cooling Capacity, Unit 1	Tons	7.5	7.5	York split type unit	
Cooling Capacity, Unit 2	Tons	10	10	York split type unit	
Set point Temprature	Deg. C	25	25	According to previous occupant	

Table 4. Internal load source or system attributes

Attributes	**Watt**	**Before**	**After**	**Before Wattage**	**After Wattage**
Washer	750	1	1	750	750
Dryer	2500	0	1	0	2500
TV	100	1	2	100	200
Refrigerator	180	1	2	180	360
Dorm Refrigerator	80	0	1	0	80
Freezer	160	1	1	160	160
Iron	1500	1	1	1500	1500
Video	60	1	1	60	60
PC	250	1	2	250	500
Vacuum	850	1	1	850	850
Stereo	35	1	1	35	35
Hair Dryer	1500	1	2	1500	3000
Electric range	7500	1	1	7500	7500
Window A/C	2000	0	1	0	2000
Toaster	700	0	1	0	700
Coffee maker	800	0	1	0	800
Cordless Phone	20	0	1	0	20
Automated Irrigation	30	0	1	0	30
Number of occupants	115	3	7	345	805
Incandescent lamp	80	42	2	3360	160
Domostic water heater	3000	1	1	3000	3000
Fluorescent lamp	80	4	42	320	3360
Thermostat Setting ^{o}F		**77**	**77**		
Total Load				**19910**	**28370**

The Investigation

The evaluation and verification of energy conservation measure (ECM) (retrofitting) is not straightforward (i.e. it is not a controlled experiment.) The occupants were different before and after ECM. The number of users, and their behavior was different. This case required a procedure that is more elaborate.

In order to overcome the effects of various parameters, it has been decided to isolate the effect of other parameters to evaluate the effect of ECM. To identify the effect of ECM on the air conditioning electrical consumption, the author calculated the non-A/C electrical consumption from the five lowest monthly bills. Then, this consumption was subtracted from the seven highest monthly bills. The remaining kwh represent the A/C electrical consumption. To identify the contribution of the building envelope to the A/C electrical consumptions, the lowest monthly bills, assumed to be the internal heat gains contribution, were identified and then divided by Coefficient of Performance (COP) of 1.7 and subtracted from A/C electrical consumption [11]. This can be inferred from the energy balance of the building and summarized as follows:

$$Y = [A + B] - [(B + C)/COP]$$

where:

Y= A/C electrical consumption due to building envelope
A= A/C electrical consumption during cooling season
B= Non A/C electrical consumption during neutral season
C= Heat gain from people
$COP = 1.7$

The author decided to use the International Performance Measurement & Verification Protocol (IPMVP) for measuring and verifying the energy and cost savings associated with energy conservation measures. IPMVP is adopted by more than 20 countries as the standard for measuring and verifying energy conservation measures (ECM). It provides an overview of the current best practice techniques available for verifying results of energy efficiency, water efficiency, and renewable energy projects in commercial and industrial facilities. It may also be used by facility operators to assess and improve facility performance. ECMs covered in the protocol include fuel saving measures, water efficiency measures, load shifting and energy reductions through installation or retrofit of equipment, and/or modification of operating procedures [12].

The IPMVP listed four options for verifying and measuring ECMs. They are used according to circumstances and context of the ECMs. They are as follows:

- Option A: Engineering calculations based on spot measurements
- Option B: Engineering calculations based on short-term monitoring
- Option C: Billing analysis at the whole-building level using statistical techniques
- Option D: Calibrated engineering simulation models

Since the whole-building's monthly bills were available during pre-retrofit and post-retrofit years, billing analysis, Option C, was used. Option C has two sub-options. One uses statistical analysis when the expected savings are less than 20%; otherwise, simple mathematical comparison is satisfactory.

The billing cycles are based on the Hijri year (lunar year) that is 11 days less than the Gregorian year. Bills are not adjusted; therefore, the monthly peak consumption is not consistent throughout the 14 billing years. The author ranked monthly bills in descending order for the pre and post ECM. By ranking, the comparison became easier and apparent.

Energy Conservation Measures

Four energy conservation measures were implemented. First, external insulation was applied to the west and north walls and two thirds of the south wall. The east wall and one-third of the South wall had been finished with marble tiles; therefore, they were left without thermal insulation. This changed the overall walls' U-value from 2.93 to 1.6 w/sq m k. Overall, roof and ceiling U-value changed from 2.9 to 0.92 w/sq m k, Table 3.

Second, gaps around two large doors and one small door were weather stripped. The gap width ranged between 6 to 12 mm pre retrofit to 1-2 mm post retrofit. Air Change per Hour (ACH) is believed to have been reduced from 2 to 0.5 ACH. Third, the gaps between sealing fresh air intake panels were reduced from 40 mm to about 1 mm. This measure and weather stripping neutralized the building pressure. Fourth, supply air diffusers area and return air grills areas were balanced. Pre-ECM diffusers' area ratio to the grills' area ratio was 2:1. The post-ECM ratio is decreased to 1:1. For more detailed data, refer to Tables 3 and 4 and Figs. 2, 3 and 4. The total cost of the EMC was SR 26000 (US$ 6933).

Results

The energy conservation measures produced satisfactory results in terms of the reduction in the average monthly bills during cooling seasons and a reduction in the annual monthly peak.

Summer average months peak loads during the pre ECM was 8855 kwh and post ECM was 7023 kwh. This translates into a 20.7% savings as shown in Table 5. Although it was not calculated, one may assume similar results in the peak cooling load (i.e. 20.7% reduction in the size of the A/C equipment). The highest peak months of electrical consumption was reduced from 10457 kwh for pre-EMC to 8169 kwh for the post-EMC (see Fig. 5). Another measure, not widely used, energy budget per occupant showed the largest savings 54% per annum (see Table 5).

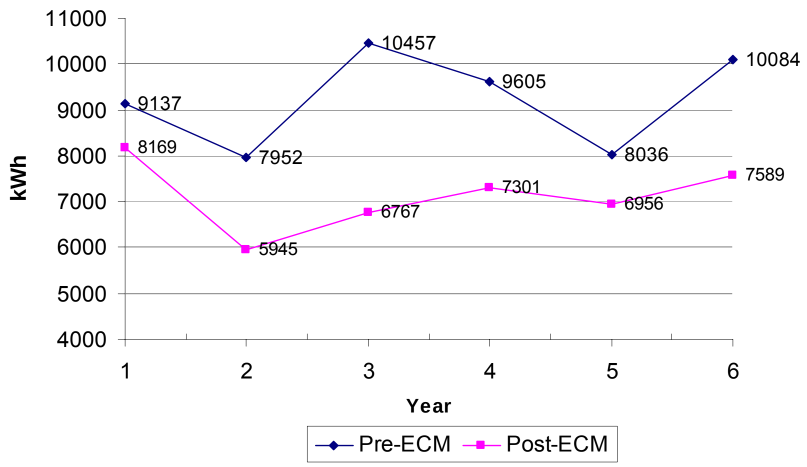

Fig. 5. Peak months electrical consumption.

Table 5. Summary of electrical energy consumption and associated savings

Items	Pre-ECM	Post-ECM
Total kwh during 6 years	253075	273717
Annual energy budget kwh/m2 (site)	134	143
Annual energy budget per occupant (kWh)	14212	6517
Monthly average kWh during 6 years	3512	3802
Summer average peak months	8855	7023
Summer average months kWh	4839	4483
Monthly average of non-A/C kWh	1022	1727
Summer A/C monthly average kWh	3817	2756
Monthly A/C electrical consumption due to bldg envelope kWh	3464	2066
Saving in monthly average due to bldg envelope		40.3%
Peak months A/C consumption due to bldg envelope kWh	3567	2343
Saving in peak months due to bldg envelope %		34.3%
Annual savings kWh (3464-2066)*7 months kWh		9782
Annual savings kWh@SR.026		2543
Cost of ECM in SR		26000
Simple payback period in years		10.2

The savings in electrical consumption due to building envelope reached 40.3% on average and 34.3% in peak months (Table 5). The average monthly consumption was 3464 kwh and 2066 kwh for pre and post ECMs respectively as illustrated in Table 5. The average peak months due to building envelope were 3567 and 2343 during pre and post EMCs Table 5. After energy auditing, the realized savings was the reduction in the A/C electrical consumption due to building envelope contribution (see Fig. 6).

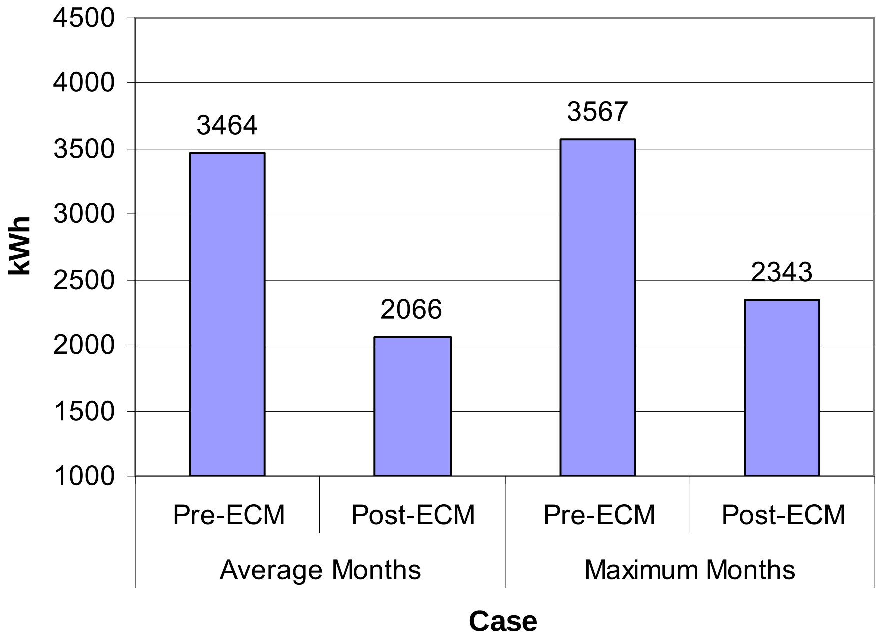

Fig. 6. A/C Electrical consumptions due to building envelope.

The widely used energy savings measures showed mixed results. The energy consumption per occupants was reduced more than 50% from the pre-ECM period. On the other hand, the annual energy budget increased by 6.7% over the pre-ECM period (see Table 5). The results of these measures compared favorably with similar results from hot-arid country [4].

Peak months electrical bills indicated significant differences between pre-ECM and post-ECM. Peak months bills during the post-ECM years were consistently less than those of pre-ECM years when compared year-by-year, as illustrated in Fig. 5.

Total electric consumption during the study’s 6-year period for the pre and post ECM does not reflect any benefits. In fact, for the post years, it is more than pre years 253075 and 273717 kwh respectively (Table 5). Non-A/C electric consumption showed similar results due to the size of the household and their associated appliances and internal heat gains.

The cost/benefit ratio is attractive to occupants. The simple payback period is 10 years (Table 5). When the A/C unit approaches the end of its life cycle, the new owner, who occupies the house after ECMs, will realize at least 21% savings in the size of the replacement unit. Although, the size of A/C unit is not determined in this study, the house needs a 14-ton unit instead of the existing 17.5-ton unit. This translates into a savings of 3.5 tons (3.5 tons @SR 5000/ton) or SR 17500. The cost of implementing ECM is SR 26,000 and the capital recovery approaches 67%. The improved thermal comfort in the house reduces the frequency of changing set point temperature by occupants, thus reducing start-ups cost.

The utility company (Saudi Electric Company) will benefit through the reduced peak demands that could increase the efficiency of the operation and utilization of power plants.

Discussion

The expected results were based on the theoretical framework governing the dynamics of heat exchange between two systems. A casual observer could not detect the savings, especially when he or she looks at the total annual consumption. After accounting for non-weather related factors, the savings become clearer. There were several assumptions made to account for non-weather related factors, such as the hours of lighting and equipment operations during the pre-ECM and post-ECM years. The non-weather related electrical consumption during pre-ECM period was 60% of the post-ECM period. Internal heat gains profile from pre-ECM and post-ECM inventories indicated a similar percentage. Pre-ECM heat gains from the inventory were 69% of the post-ECM. The differences between 60% and 69% may be attributed to the life-style of the two households during pre and post EMCs years.

The new air conditioning units are more efficient, the new standards mandates SEER 10, i.e. COP of 2.9 versus 1.7 of pre-1990 models. The expected electrical consumption due to space cooling could be reduced by more than 40% when using new model.

Although the control in this study was minimal, the differences between pre-ECM and post-ECM electrical consumption is significant. The results are comparable with several local and international studies.

Conclusion

Energy conservation measures saved energy and reduced peak loads. These measures are economically attractive to the consumers. Discounting non-weather related factors were very helpful in determining the contribution of the building envelope to the A/C electrical consumption. This case can be replicated in uninsulated-old residential buildings especially when the A/C system is due for replacement.

Acknowledgment. I would like to thank SCECO east, billing department for furnishing the monthly bills for 14 years. My appreciation to Engineer Khaled Al-Mulla for the users' profiles and inventory of heat gains sources for the pre-ECM period. My appreciation goes to Dr. Elbashir for his constructive comments and to Mrs. Judith A. Khan for proofreading the manuscript.

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استهلاك الطاقة الكهربائية قبل وبعد تطبيق بعض إجراءات المحافظة عليها: حالة دراسية لمبنى سكني من طابق واحد يقع في الظهران بالمملكة العربية السعودية

إبراهيم بن عبدالله المفيز

أستاذ مشارك ، كلية العمارة والتخطيط, جامعة الملك فيصل, الدمام, المملكة العربية السعودية

بريد إلكتروني: ***ibraheem@kfu.edu.sa***

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ملخص البحث. تعرض الورقة نتائج التوفير في استهلاك الطاقة الكهربائية لمبنى سكني من طابق واحد بعد إعادة تأهيله ليكون اقتصاديا في استهلاك الطاقة الكهربائية المستخدمة في التكييف. يقع المبنى في حي الدوحة في الظهران. تم تسجيل والحصول على بيانات الفواتير الشهرية لمدة ١٤ سنة واستخدم منها ٧٢ شهرا قبل التأهيل و ٧٢ شهرا بعد التأهيل. استخدم في هذه الدراسة البروتوكول الذي تصدره اللجنة الدولية للقياس والتأكد من أداء الإجراءات المطبقة لتوفير الطاقة ، إضافة إلى تغيير الخصائص الفيزيائية للمبنى لتأهيله. تغير مستخدمي المبنى من حيث العدد ونمط الحياة وتجهيز المبنى ، وانعكس التغيير على المعدل الشهري لاستهلاك الكهرباء في الأشهر التي لا يستخدم فيها المكيف, ١٠٢٢ كيلوات/ساعة قبل و ١٧٢٧ كيلوات/ساعة بعد التأهيل. قام الباحث بحساب استهلاك المكيف من الكهرباء قبل وبعد تأهيل المبنى للمقارنة وحساب التوفير، وأثبتت النتائج توفيرا يقارب ٤٠٪ في معدل الاستهلاك الشهري الكهربائي للتكييف, ويمكن القول إن توفيرا يقارب ٣٤٪ قد تحقق في معدل استهلاك أشهر الذروة (يوليو وأغسطس). ويكمن الاستنتاج أن حمل التكييف في ساعة الذروة سوف يقل بنفس النسبة.