Comparative Study of the Electrical Energy Consumption and Cost for a Residential Building with Conventional Appliances Vis-a-Vis One with Energy-Efficient Appliances

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1 Introduction

This energy is an important recipe for the economic growth and development of nations. It is pertinent that energy is properly conserved in order to prevent avoidable waste of energy which will drastically reduce cost and the need to generate more energy to meet the national demand. Energy demand in Nigeria is expected to grow explosively in proportion to the anticipated rapid population growth between 2015 and 2050. The efficiency with which energy is used by firms and households has widespread impact on economic activity of the country, which in turn has implications for environmental quality and energy security. Buildings account for more than 40%

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of the global energy use today in both developed and developing countries [1]. Hence, it poses a major opportunity as a sector for consideration to reduce global energy consumption in Nigeria. A community with efficiently designed homes and offices will lower energy bills, liberate investible assets, and avoid unnecessary expenditure like building new power plants [2].

Energy efficiency in buildings has been relatively well researched, yet the problem of energy inefficient buildings in Africa still persists. The regulatory and voluntary approaches for enhancing building energy efficiency were reviewed in [3]. The opportunities and challenges to electrical energy conservation and CO_2 emissions reduction in Nigeria's building sector were evaluated in [4]. A paper review toward sustainable, energy-efficient, and healthy ventilation strategies in buildings was considered in [5].

Energy consumption in buildings includes lighting, domestic and commercial appliances, warming, ventilation, and cooling systems. Some inventive progresses have been made in energy-efficient buildings, and there is a progressing exertion in advancing and showing their energy savings' possibilities. However, the majority of these solutions are directed toward new buildings and future building designs, and is difficult to implement in existing buildings [5]. Although energy-efficient appliances promise savings in the cost incurred on energy consumptions, the replacement of old and inefficient appliances in old buildings in Nigeria is coming at a slow pace. This is because of the high cost that comes with replacing the appliances as most energy-efficient appliances are more costly than their equivalent inefficient appliances. It is therefore important to evaluate if the saving on energy consumptions by using an energy-efficient appliance will pay for the cost incurred to replace such appliance with an energy-efficient one within the expected life expectancy of the appliance. Against this background, this paper aims to design a framework to improve the energy efficiency of buildings in Nigeria to curb carbon emissions and increase energy savings. These innovative solutions will lead to sustainable development in the energy sector and the Nigerian economy. There is a lack of adequate literature to solve the inefficiency of buildings in the country. This paper therefore aims to design a framework for improving the energy efficiency of buildings in Nigeria.

This paper is structured as follows: The next section reveals some of the literature that were reviewed, followed by an explanation of the methodology implored and then a discussion of the result obtained and the paper was concluded.

2 Literature Review

According to [6], there is an inefficient utilization of available energy in Nigeria. Currently, most buildings in Nigeria lay more emphasis on the aesthetic values with little or no consideration for energy efficiency [7]. A more efficient utilization of energy resources can lessen greenhouse gas emissions and slow down depletion of nonrenewable energy resources [3].

Energy efficiency in buildings has been relatively well researched, yet the problem of energy inefficient buildings in Africa still persists. The regulatory and voluntary approaches for enhancing building energy efficiency were reviewed in [3]. They observed that the potential energy cost saving alone is an inadequate motivation to investing into improvement measures, unless there is an energy price shock. They recommended the adoption of a well-articulated policy mix involving both regulatory and voluntary instruments to achieve energy efficiency in buildings.

The opportunities and challenges to electrical energy conservation and CO_2 emissions reduction in Nigeria's building sector were evaluated in [4]. They found that putting all the energy saving opportunities they identified in place, at least 10% of total residential electrical energy use could be conserved while about 10% of both total industrial and commercial sectors electricity demand could be saved. These would significantly cut greenhouse gases emissions in the country. A framework of strategies to overcome these problems, encourage energy conservation, and thereby enhance sustainable development in Nigeria was then suggested. The need for energy-efficient buildings in Nigeria was evaluated in [8]. It was found that in Nigeria, most buildings do not take solar architecture and energy efficiency into consideration during construction due to ignorance, poverty, lack of awareness, and/or improper government policy on building regulations. The author addressed these issues by proffering solutions on the way forward for the country to achieve energy efficiency in buildings. A potential analysis of gray energy limits for residential buildings in Germany was performed in [9]. It was observed that the global warming potential (GWP) of shell constructions could be reduced by as much as 77% using existing technologies and with no additional investment costs. Environmental cost savings of more than €1 billion per year could be realized for investments in the German economy. With additional investments, the saving potential could jump to 95%.

A paper review toward sustainable, energy-efficient, and healthy ventilation strategies in buildings was considered in [5]. Evidence suggested that utilizing hybrid ventilation in buildings integrated with appropriate control strategies, to adjust between mechanical and natural ventilation, leads to substantial energy savings, while an appropriate indoor air quality is still maintained. A model-based optimization of distributed and renewable energy systems in buildings to address the design and control problem of building energy systems was developed in [10]. They developed a two-level optimization framework for the research. The results provided different optimal trade-off unit configurations with respect to the total investment cost and the defined self-sufficiency indicator. Despite the fact that this study solely considered typical Swiss residential dwellings, the presented framework could be applied in other types of buildings.

There is a lack of adequate literature to solve the inefficiency of buildings in the country. This paper therefore aims to design a framework for improving the energy efficiency of buildings in Nigeria.

3 Proposed Methodology

3.1 Case Study: Three-Bedroom Flat in Covenant University Ota

Covenant University is a growing community with over ten thousand people [11]. Domiciled in the mini-township is a gas-powered turbine. The energy use in the community ranges around 2 MW of peak load when the university is in full session and 1.25 MW of peak load when the university is not in session as shown in Fig. 1.

Figure 1 depicts a graphical representation comparing the peak loads in Covenant University when the school is on session and when out of session. Its graph shows that the peak load experienced during session is relatively high when compared to off session consumption. The electricity tariff for the residents of the Covenant University is ₦30 per kWh. Comparing this tariff with the current tariff set by the Nigerian Electricity Regulation Commission (NERC) effective from February 1, 2016, it can be seen that there is a tariff difference as shown in Table 1. This tariff in Table 1 is exclusively for residential houses.

Table 1 shows the energy cost of different classes of residence from 2015 to 2016 by Ikeja Distribution Company. The difference in the energy charges has increased tremendously from R2SP to R4 (H max demand—11/33 kV) class of residence ranging from 8 to 10.67 naira. The residents of this community enjoy 24-hour electricity supply and do not have to purchase or maintain backup generators like their counterparts living elsewhere, but it is also important for the members of this community to

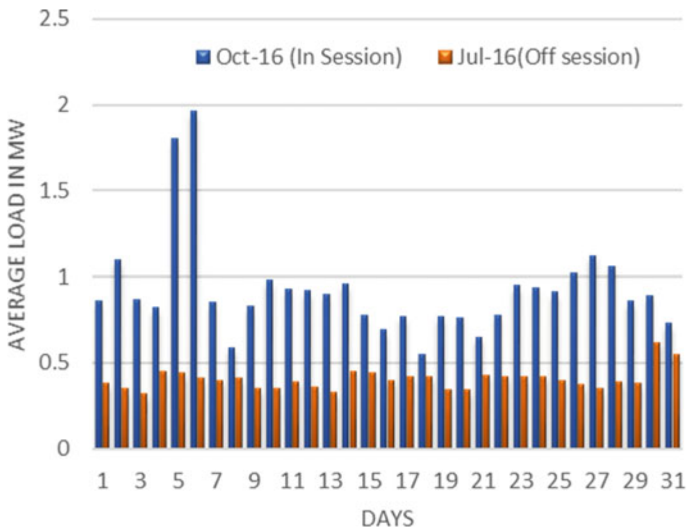

Fig. 1 Graph showing a comparison of the peak loads experienced in Covenant University when the University is in session and out of session

Table 1 Ikeja distribution company's energy charges in ₦/kWh [12]

Class of residence	2015 (Naira)	2016 (Naira)	Naira difference in 2016
R1 (Lifeline 50 kWh)	4.00	4.00	0.00
R2SP (Single phase)	13.21	21.30	8.09
R2TP (Three phase)	13.21	21.80	8.59
R3 (LV Maximum Demand)	26.25	36.49	10.24
R4 (HV Maximum Demand—11/33 kV)	26.25	36.92	10.67

imbibe the energy efficiency paradigm. Not only will this reduce the cost of energy used but also it will make more energy available for the ever-increasing community.

3.2 Building Description (AS-IS)

- **Building envelope**: The building is 12-year-old, built with sandcrete blocks and has an aluminum roof finish.
- **HVAC system**: The building has a total of four-wall unit air conditioners located in various spaces of the house. All rooms have additional ceiling fans, while the living room has two ceiling fans.
- **Water management**: There is a centralized water pumping system for the members of the community. However, each of the houses has its own water heating system. In the audited house, the distributed water heating method was used and there is a total of three 15 L Ariston water heaters on in each of the bathrooms catering to the hot water needs of the family.
- **Appliances**: The appliances consuming the most electricity are the air conditioners and the water heaters. In most space in the building, incandescent bulbs were used for the lighting.

3.3 Energy Demand and Cost of the Building AS-IS

Based on the load schedule in Fig. 2 and the walk-through energy audit carried out on the residence, the energy demanded annually by each appliance installed was computed using Eqs. 2, 3 and using Eq. 4, and the energy cost was computed. Results can be found in Table 2. The following equations [13] are used to estimate the energy parameters:

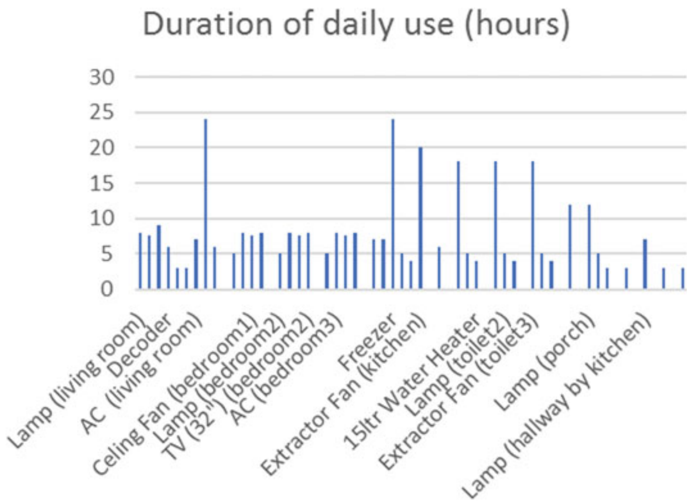

Fig. 2 Load schedule of the residence

Table 2 Comparison of the current energy consumption, retrofit energy consumption, and savings

Model	Annual energy consumption (kWh)	Annual energy cost (₦ 30/kWh)
Building as-is	80, 211.1225	2,406,333.68
Building as-can-be	42,052.38	1,261,571.4
Savings	38,158.7425	1,144,762.28

$$\text{power} = \text{energy}/\text{time}. \quad (1)$$

$$\text{Energy demand (ED)} = \text{Power consumption x time taken} \quad (2)$$

$$\text{Annual Energy Demand (AED)} = \text{ED} \times 365 \quad (3)$$

$$\text{Annual Energy Cost (AEC)} = \text{AED} \times \text{tarrif}/\text{kWh} \quad (4)$$

The installed energy demand in the residence (this is based on the appliances present in the house) is **80, 211.1225 KWhr** with an energy cost of **2,406,333.675 Naira**.

4 Comparison Result and Discussions

4.1 Recommendations of Energy-Efficient Methods (As-Can-Be)

Some of the proposed methods of energy efficiency for the audited building are as follows:

A. **Centralized water heating system**:

There are two major alternative solutions to the water heating consumption in the household:

- Centralized heating;
- More energy-efficient distributed water heaters.

Centralized heating is more energy-efficient as they provide hot water at the points of need. Also, the heat losses associated with storage tank distributed water heaters are also nonexistent. The centralized water heating was implored in our model. In place of the three distributed 15 L water heaters, one centralized 50 L water heater is to be used in our model to deliver hot water need to each of the three bathrooms.

B. **Appliances**: Replacing the appliances with energy star-rated devices will go a long way in increasing the energy efficiency of the household. The models of energy-rated refrigerators sold nowadays use less than half the amount of energy of models sold before 1993, effectively reducing the energy consumption by 50% [14]. Similarly, the air conditioners in the house can be retrofitted with more energy-efficient versions.
C. **Lighting**: Replacing the incandescent bulbs in the house with CFLs and LEDs should go a long way in reducing the energy consumption of the building by lighting. Homeowners have a proclivity of leaving lights in certain rooms on when not in use like the kitchen, store, and the restroom. Installing an occupancy in these rooms ensures that the lights are only on when they are occupied.

4.2 Energy Demand and Cost of the Retrofitted Model (As-Can-Be)

Based on the above-proposed solutions, an energy-efficient model of the building was designed. The inefficient appliances were substituted with energy-efficient appliances. The annual energy demand and cost was computed for the retrofitted model result as shown in Table 3; the estimated energy demand for the model building (as-can-be) is 42,052.38 KWh with the energy cost of 1,261,571.4 Naira. The retrofitted model in comparison to the building as is shown that by retrofitting the house with energy-efficient appliances 47.57% (38,158.7425 kWh) is saved yearly on energy demanded.

Table 3 Table showing the annual energy demand and cost of each appliance in the building as-is and as-can-be

S/n	Area	Appliance (type)	Appliance rat (W) current	Appliance rat (W) retrofit	Duration of use per day (h)	Annual energy demand (As-is) (kwh)	Annual energy demand (as-can-be) (kwh)	Annual energy savings (kwh)
1	Living room	Lamp	60 × 10	20 × 26	8	1752	1518.4	233.6
		Celling fan	75 × 2	30 × 2	7.5	410.63	164.25	246.375
		TV (42″)	120	54	9	394.2	177.39	216.81
		Decoder	100	100	6	219	219	0
		DVD	50	50	3	54.75	54.75	0
		Sound system	150	65	3	164.25	71.175	93.075
		AC	2700	1340	7	6898.5	3423.7	3474.8
		Dispenser	580	580	24	5080.8	5080.8	0
		Electric iron	1500	1500	6	3285	3285	0
		Lamp	40 × 4	20 × 6	5	292	219	73
2	BedRoom1	AC	2700	1340	8	7884	3912.8	3971.2
		Celling fan	75	30	7.5	205.31	82.125	123.1875
		TV (32″)	105	31	8	306.6	90.52	216.08
		Lamp	40 × 4	20 × 6	5	292	219	73
3	BedRoom2	AC	2700	1340	8	7884	3912.8	3971.2
		Celling fan	75	30	7.5	205.31	82.125	123.1875
		TV (32″)	105	31	8	306.6	90.52	216.08
		Lamp	40 × 4	20 × 6	5	292	219	73

(continued)

Table 3 (continued)

S/n	Area	Appliance (type)	Appliance rat (W) current	Appliance rat (W) retrofit	Duration of use per day (h)	Annual energy demand (As-is) (kwh)	Annual energy demand (as-can-be) (kwh)	Annual energy savings (kwh)
4	BedRoom3	AC	2700	1340	8	7884	3912.8	3971.2
		Celling fan	75	30	7.5	205.31	82.125	123.1875
		TV (32″)	105	31	8	306.6	90.52	216.08
		Lamp	40 × 2	20 × 3	7	204.4	153.3	51.1
		AC	2700	1340	7	6898.5	3423.7	3474.8
		Freezer	1600	500	24	14016	4380	9636
5	Kitchen	Elect. kettle	2000	2000	5	3650	3650	0
		Microwave	1400	1000	4	2044	1460	584
		Ext. fan	6	6	20	43.8	43.8	0
6	Store	Lamp	20	8	6	43.8	17.52	26.28
		Ext. fan	6	6	18	39.42	39.42	0
7	Toilet1	Lamp	40	20	5	73	36.5	36.5
		H_2O heater	1500	0	4	2190	0	2190
		Ext. fan	6	6	18	39.42	39.42	0
8	Toilet2	Lamp	40	20	5	73	36.5	36.5
		H_2O heater	1500	0	4	2190	0	2190
		Ext. fan	6	6	18	39.42	39.42	0

(continued)

Table 3 (continued)

S/n	Area	Appliance (type)	Appliance rat (W) current	Appliance rat (W) retrofit	Duration of use per day (h)	Annual energy demand (As-is) (kwh)	Annual energy demand (as-can-be) (kwh)	Annual energy savings (kwh)
9	Toilet3	Lamp	40	20	5	73	36.5	36.5
		H_2o heater	1500	0	4	2190	0	2190
10	Terrace	Lamp	40 × 2	20 × 3	12	350.4	262.8	87.6
		Lamp	40	20	12	175.2	87.6	87.6
11	Porch	H_2O pump	400	400	5	730	730	0
		Washing machine	500	500	3	547.5	547.5	0
12	Ent. Porch	Lamp	40 × 2	20 × 3	3	87.6	65.7	21.9
13	Hallway1	Lamp	40	20	7	102.2	51.1	51.1
14	Hallway2	Lamp	40	20	3	43.8	21.9	21.9
15	Hallway3	Lamp	40	20	3	43.8	21.9	21.9
Total energy (kWh)						80, 211.1225	42,052.38	38,158.7425
Total cost (Naira)						2,406,333.68	1,261,571.4	1,144,762.28

4.3 Comparative Analysis of the Current Model and the Energy-Efficient Model

The total power demand from the current energy consumption model is about 80, 211.12 kWh, while the energy demand using the energy-efficient method (Building as-can-be) is 42,052.38 kWh. This results in a considerable decrease in the energy demanded and used by the household, and about 38,158.7425 kWh of energy saved yearly. This amount of energy saved can be used elsewhere, thereby reducing the need to create more power plants and eventually reducing carbon emission in the country. The total cost of running the current energy consumption model amounts to about ₦2,406,333.68 spent yearly. By implementing the retrofit/energy-efficient method, this could be reduced to ₦1,261,571.4 such that ₦1,144,762.28 would be saved per year Fig. 3.

4.4 Payback Period (PBP) of Retrofit Appliances

Energy-efficient appliances usually cost more than non-energy-efficient appliances. Before retrofitting is performed in a building, it is important to investigate and compare the payback period of the appliance against the life expectancy of that appliance. Retrofitting is usually performed when the payback period of the appliance is lesser than its life expectancy [15, 16]. The payback period of an item is given as the ratio between cost of purchasing the unit and the cost of energy saved per year. A breakdown of the PBP of some targeted electrical appliances in the house is given in Table 4. It can be seen that all of the retrofitted items provide more energy savings in the long run. Items like the energy-rated star ceiling fan in Bedroom1, which may cost about ₦9800, could save as much as 123.19 kWh/year and ₦ 3695.63 in energy

Fig. 3 Comparison between energy consumption and energy savings

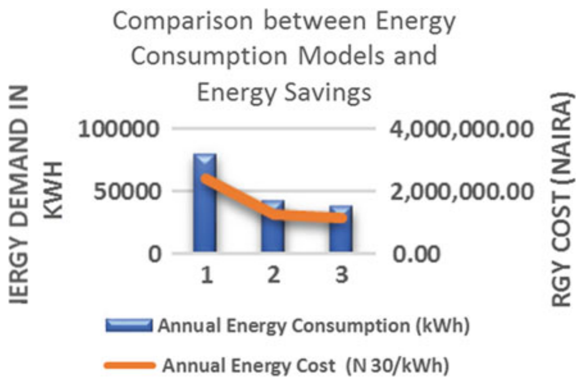

Table 4 Retrofitted electrical appliances, energy demand savings per year, energy cost savings per year

S/n	Area	Appliance (type)	Building (As-is) appliance rat (W)	Building appliance rat (W)	Cost of annual energy saved	Cost of purchasing energy-efficient appliance	Payback period (years)	Life expectancy (years)	Decision
1	Living room	Lamp	60 × 10	20 × 26	7,008.00	21,021.00	3.00	2.74	FALSE
		Ceiling fan	75 × 2	30 × 2	7,391.25	9,800.00	1.33	13.00	TRUE
		TV (42″)	120	54	6,504.30	135,000.00	20.76	18.00	FALSE
		Sound system	150	65	2,792.25	42,800.00	15.33	15.00	FALSE
		AC	2700	1340	104,244.00	108,500.00	1.04	13.00	TRUE
		Lamp	40 × 4	20 × 6	2,190.00	4,851.00	2.22	4.38	TRUE
2	BedRoom1	AC	2700	1340	119,136.00	108,500.00	0.91	13.00	TRUE
		Ceiling fan	75	30	3,695.63	9,800.00	2.65	13.00	TRUE
		TV (32″)	105	31	6,482.40	80,000.00	12.34	18.00	TRUE
		Lamp	40 × 4	20 × 6	2,190.00	4,851.00	2.22	4.38	TRUE
3	BedRoom2	AC	2700	1340	119,136.00	108,500.00	0.91	13.00	TRUE
		Ceiling fan	75	30	3,695.63	9,800.00	2.65	13.00	TRUE
		TV (32″)	105	31	6,482.40	80,000.00	12.34	18.00	TRUE
		Lamp	40 × 4	20 × 6	2,190.00	4,851.00	2.22	4.38	TRUE
4	BedRoom3	AC	2700	1340	119,136.00	108,500.00	0.91	13.00	TRUE
		Ceiling fan	75	30	3,695.63	9,800.00	2.65	13.00	TRUE

(continued)

Table 4 (continued)

S/n	Area	Appliance (type)	Building (As-is) appliance rat (W)	Building appliance rat (W)	Cost of annual energy saved	Cost of purchasing energy-efficient appliance	Payback period (years)	Life expectancy (years)	Decision
		TV (32″)	105	31	6,482.40	70,000.00	10.80	18.00	TRUE
		Lamp	40 × 2	20 × 3	1,533.00	2,425.50	1.58	3.13	TRUE
		AC	2700	1340	104,244.00	108,500.00	1.04	13.00	TRUE
5	Kitchen	Freezer	1600	500	289,080.00	115,200.00	0.40	15.00	TRUE
		Microwave	1400	1000	17,520.00	58,000.00	3.31	10.00	TRUE
6	Store	Lamp	20	8	788.40	1,960.00	2.49	11.42	TRUE
7	Toilet1	Lamp	40	20	1,095.00	808.50	0.74	4.38	TRUE
8	Toilet2	Lamp	40	20	1,095.00	808.50	0.74	4.38	TRUE
9	Toilet3	Lamp	40	20	1,095.00	808.50	0.74	4.38	TRUE
10	Terrace	Lamp	40 × 2	20 × 3	2,628.00	2,425.50	0.92	1.83	TRUE
11	Porch	Lamp	40	20	2,628.00	808.50	0.31	1.83	TRUE
12	Entrance Porch	Lamp	40 × 2	20 × 3	657.00	2,425.50	3.69	7.31	TRUE
13	Hallway1	Lamp	40	20	1,533.00	808.50	0.53	3.13	TRUE
14	Hallway2	Lamp	40	20	657.00	808.50	1.23	7.31	TRUE
15	Hallway3	Lamp	40	20	657.00	808.50	1.23	7.31	TRUE

cost per year. The life expectancy of the ceiling fan is 13 years, and the expected payback period calculated with Eq. 4 for the ceiling fan is 2.65 years. Since the life expectancy of the appliance is greater than its payback period, it is economically viable to substitute the current appliance with an energy-rated one. This means that in about two and half years, the ceiling fan would have paid for itself through its savings on energy cost. After which it will continue to save energy cost. The life expectancy of an item is subject to how to appliance is used and maintained by the owners. If an appliance is used and maintained properly, it may last longer than its initial design considerations [17]

$$\text{PBP} = \text{Cost of purchasing unit/Energy cost saved per year} \tag{5}$$

The payback period of each substituted appliance was calculated using Eq. 5. An interactive MATLAB program (Appendix A) was written to help users determine whether or not it is economically viable to buy any energy-efficient appliance.

After calculating the payback period for each energy-efficient appliance, the payback period in years was compared to the life expectancy in years given by the manufacturer to see if it is economically viable to purchase the appliance or not. It was determined that when the life expectancy is greater than the payback period, it is economically viable to purchase the appliance; otherwise, it is not. The decision column in Table 4 shows which appliance is economically viable to purchase, where "TRUE" means to purchase and "FALSE" means do not purchase.

5 Conclusion

This paper reveals more insight into how an as of now existing building can be retrofitted to be more energy-efficient. A stroll through energy review was done taking a standard three-bedroom flat in Covenant University as contextual analysis. It is trusted that by adopting energy-efficient technologies and retrofitting the house in that order, family units in Covenant University will have the capacity to spare more cash over the long haul, and furthermore this will come about into more energy for use in the community. The retrofitted model demonstrates that about 47.5% of the cost of energy utilized yearly can be saved. By replicating this model to every one of the family units inside the community, more energy would be spared all things considered and there would be little need to expand the generating limit of the community later on even with the energy requirements of its regularly expanding populace.

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