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Evaluation of Electrical Power Consumption and Reducing the Thermal Cooling Load for Academic Facilities in Iraq

Nassr F. Hussein*, Ali A. Ismaeel, Walaa M. Hashim

College of Electromechanical Engineering, University of Technology-Iraq, Baghdad 10066, Iraq

Corresponding Author Email: 50153@uotechnology.edu.iq

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ABSTRACT

Although Iraq's electricity net generation grew more than 11% after the 2003 war, reaching 16.9 megawatts in 2017, electricity production is short by more than 10 megawatts, according to the last annual report of the Iraqi Ministry of Electricity in 2019. Therefore, to cope with the negative effects produced by the electricity shortage crisis, a new policy of energy saving in Iraq's buildings has been presented in this study. The academic buildings were selected as a case study, and three strategies were adopted in this study: First, replacing the conventional lighting system with the LED lighting system. Secondly, utilizing an economical ventilating system based on ceiling fans with hidden blades instead of the old conventional ventilating system. Thirdly, reducing the cooling load requirements by reducing the building rooms' volume through the installation of secondary roofs. The results show that both the electrical power consumption and the cooling load requirements were reduced after adopting the new strategies, in which the strategies of applying the LED lighting system and the secondary roofs contributed to saving about 93.3% and 39.5% of the power consumption, respectively, and saving energy of about 66577.8 kWh from the required total cooling load. Moreover, using both LED lighting systems, an economical ventilating system, and secondary roofs contributes to saving about 93%, 32.8%, and 39.5%, respectively, of the annual cost.

1. INTRODUCTION

Iraq is one of the richest countries in the world in terms of resource diversity and potential investment. The resources are distributed in different regions along the Iraqi area, which is 437,072 km^2. In Iraq, oil is the main energy source that supplies the industrial infrastructure and is also the country's main economic resource through selling surplus quantities to global markets. Iraq's oil production after 2003 reached three million barrels, according to data from the "Organization of the Petroleum Exporting Countries (OPEC)", and the number of oil reserves reached second place after Saudi Arabia, by nearly 300 billion barrels [1].

Nevertheless, despite Iraq's ability to produce huge quantities of oil, it is suffering from a severe crisis in electrical power generation, which seriously threatens Iraq's industrial and urban development programs. According to the last annual report of the Iraqi Ministry of Electricity in 2022, electricity generation has reached more than 15,000 megawatts, as shown in Table 1 [2]. In contrast, the real Iraqi need is more than 30,000 megawatts [3].

The great shortage in electricity generation after 2003 may be attributable to several reasons involving the ageing of most power stations, in addition to the weakness in the upgrade and maintenance process for these stations, the failure to implement the construction of new stations according to the specified schedule, and the complexity of the governmental routine in contracting with implementation companies. In addition to previous reasons, the government's policy related to spreading the reduction of energy consumption's policy in society is itself a weakness that leads to an increase in the energy consumption level [4]. Moreover, the dramatical increment in the population of Iraq (from 14 million in 1980 to 32 million in 2010 and is expected to reach 64 million by 2050 based on the Ministry of Planning and Development Cooperation data) [5], has been accompanied by an increase in educational facilities, where the education institutions reach more than 10,000 institutions with different educational levels, as explained in Figure 1 [6].

Activating the energy rationalization policy and management in buildings is an important step for energy demand reduction and a step towards creating a sustainable environment in Iraq. Many researchers in the world, especially in Iraq, have invested their efforts in investigating different types of energy efficiency systems in several building applications. For instance, Jassem [7] studied improving the lighting system efficiency of a leather industry factory in Al-Najaf City, Iraq, by reducing electrical consumption. Müllner and Riener [8] used a smart lighting system in public street lighting by taking advantage of reducing the light intensity or turning off the lights when there is no real use for them in the streets. In the same context, Akar et al. [9] used a smart lighting system that depended on a time control approach, and the proposed method saved about 71.4% of annual energy consumption. Akkar and Mohammed [10] used a smart technique based on the Field Programmable Gate Array (FPGA) to manage the lighting system's power consumption, and they reduced the energy consumption by about 63%.

Table 1. Actual production rate of different electric power plants in 2022 [2]

Type of Electric Power Generation Stations	Actual Production Rate (MW)
Steam power plants	3301
Gas power plants	9056
Hydroelectric stations	303
Electricity Ministry diesel units	533
Imported electric power	2745

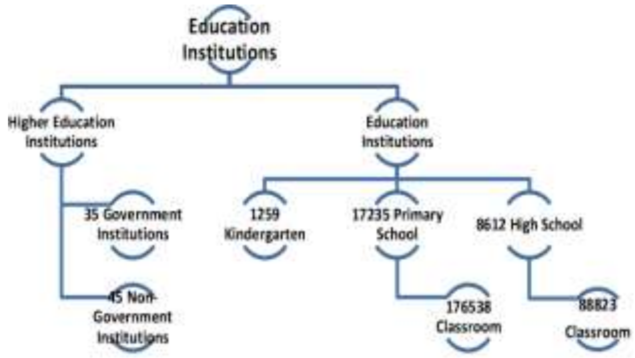

Figure 1. Number of educational institutions in Iraq [6]

Cooling load is another important sink of energy in educational institutes. Ahn et al. [11] studied the feasibility of reducing the cooling load by reducing the heat emitted from LED bulbs, and they did that by adding an air heat exchanger to cool the bulbs, and they succeeded in reducing the cooling load by 19.2%. Ahn et al. [12] experimentally investigated the process of controlling the lighting during the night and day to achieve lower electric power consumption and higher cooling in the summer season. Azis [13] studied the influence of utilizing LED lighting systems on energy consumption in different types of buildings in Malaysia. The researchers revealed that using LED lighting systems can reduce energy consumption by about 4% annually when adopting LED lighting systems instead of conventional lighting systems. Al Rashdi et al. [14] proposed using LED lighting systems in educational facilities in Oman and studied the impact of the proposed lighting system on saving energy and its cost. The study showed that the proposed lighting system could minimize energy consumption by about 16% per year and save about 16919 Riyal Omani annually. Song et al. [15] indicated in their investigation that using an LED lighting system can reduce the energy consumption of air-conditioning systems due to the lower heat emission from LEDs. The researchers indicated that the room's interior air temperature rose only by 0.2 degrees centigrade when using LED bulbs. Sonne and Parker [16] used 10 ceiling fans with thermostats, which were equally divided into two groups between houses in Miami City. The researchers tested these fans for one year and found that the cooling load decreased by 15%. Faraji [17] also studied using ceiling fans in the building theoretically and found the possibility of reducing room temperature by up to 40%. In the same context, Wakamatsu et al. [18] symmetrically used ceiling fan lines to increase the air velocity in the room centre without generating noise in the room. Luo et al. [19] investigated the working way of ceiling fans in four selected buildings that include different types of spaces. The study covered different parameters, namely, the type of ceiling fan, the number of fans' operation, the direction of operation, the room's geometry, including shape, size, and fans' location, and the density of furniture within the room. The study concluded that the ceiling fans' layout can affect the magnitude of air speeds and their uniformity within a space. Moreover, distributing the fans over a specified area evenly produces higher average air speeds and more uniform air distribution. Bamdad et al. [20] studied the influence of ceiling fans on reducing the cooling load in buildings in Australia. The study outcomes indicated that ceiling fans can save 23% of total energy consumption. Mehmood et al. [21] investigated the feasibility of using a ceiling fan system without blades as an alternative to a conventional ceiling fan system. The researchers revealed that, as compared with the conventional ceiling fan system, there is an improvement of 60% in air delivery when using the proposed fan system.

Hassan [22] studied the influence of changing the orientation, materials, and positions of buildings on the amount of energy consumption. The study has been conducted on selected buildings in Iraq. The outcomes of this study revealed that changing buildings' positions saves about 14% of energy consumption, while changing buildings' orientations can save about 8-23% of energy consumption. Salih [23] used locally available materials to improve heat transfer reduction for existing buildings' roofs, and she found that using these materials can reduce cooling loads by 30%. Mahmood et al. [24] investigated the feasibility of utilizing materials that are available in local markets as thermal insulation inside the residential buildings' walls to minimize the amount of heat transfer through walls and thus lower cooling load requirements. The proposed materials included grains of cork, cane mat, and sawdust wood. The results showed a reduction in cooling load requirement by about 40%, 44%, and 50% when using grains of cork, cane mat, and sawdust wood inside the building's walls. Jia et al. [25] investigated the impact of implementing green-cool roofs on reducing the annual energy consumption of buildings. The outcomes of this study revealed that proposed roofs succeeded in lowering the annual energy consumption of HVAC systems in buildings by about 65 to 71%. Shahee et al. [26] studied the possibility of reducing the consumption of energy in a building located in Florida, USA, by adopting two scenarios, namely: The first scenario is using insulation and shading, and the second scenario is achieving a building with zero energy by utilizing the photovoltaic systems on the building's roof. The results showed the feasibility of minimizing the consumption of energy in the building by about 81% by applying the proposed scenarios. Long et al. [27] studied numerically the impact of coupling solar chimneys with earth-air heat exchangers on reducing the indoor temperature of buildings and hence on reducing the consumption of energy by HVAC systems. The outcomes of this study indicated that the proposed system could reduce the indoor temperature of the building by up to 4.4℃. Abdalazeem et al. [28] studied experimentally the impact of various types of green roofs (vegetation, clay, and sandy soil) on minimizing the cooling load. The results revealed that the maximum reduction in cooling load (10.75%) was achieved when using a clay roof.

From previous studies, it is noted that the studies focused on using a single application or a single energy consumption rationalization policy, and these policies were limited to general residential or industrial applications. Educational facilities have not received sufficient attention in studying methods for thermal cooling load reduction and energy conservation, especially in Iraq, which is a country that suffers from a major electricity shortage.

The current research aims to apply different strategies and study their feasibility in saving buildings' energy consumption, especially in educational facilities. Three simple and applicable strategies have been evaluated, namely, replacing the conventional lighting and ventilating systems with new efficient systems that consume less electrical power and reducing the building's classroom size by installing secondary roofs to reduce the cooling load requirements. In addition, this study also aims to develop the electricity consumption policy and management in Iraq.

2. METHODOLOGY

2.1 Case study

The electromechanical engineering department (Previously called the Technical Education Department), located at the University of Technology, Baghdad, Iraq, as shown in Figure 2, was chosen as a building model to apply the proposed strategies of the present work.

The purpose of this academic facility is to prepare specialists in the region of Electromechanical engineering. This department is divided into five branches: the Electromechanical Engineering Systems Branch, the Energy and Renewable Energies Engineering Branch, the Navigation and Guidance Engineering Branch, the Oil and Gas Equipment Branch, and the remotely piloted aircraft engineering branch.

The building consists of three levels. The first includes eight classroom halls, Seminars and conference halls. The second contains the Offices of the heads of the five scientific branches, the offices of the branch rapporteurs and the secretaries, the Student Affairs and Registration division, lab rooms, and Seminars Hall. The third contains the Office of the head department, the Office of the Department Council, management rooms, and staff rooms.

The building consists mainly of several classrooms (8 classrooms), which are occupied by students for six hours a day, five days a week, for two academic semesters. Moreover, the building also contains halls for seminars, conferences, and administrative offices. The classrooms previously included an old lighting system that depended on using tungsten lights, which consumed a large amount of electrical power besides emitted a large amount of heat. Furthermore, the ventilating system that is used in these classrooms is a conventional old type that includes ceiling fans with visible blades. In addition, the classrooms are without secondary roofs. The strategies that are used in this work are described as follows: the first strategy involved replacing the old conventional lighting system with a new economical LED lighting system, the second strategy involved replacing the old conventional ventilating system with a new economical ventilating system that depends on using ceiling fans with hidden blades, and the third strategy involved installing secondary roofs to reduce the building's room volume, hence reducing the cooling load requirements.

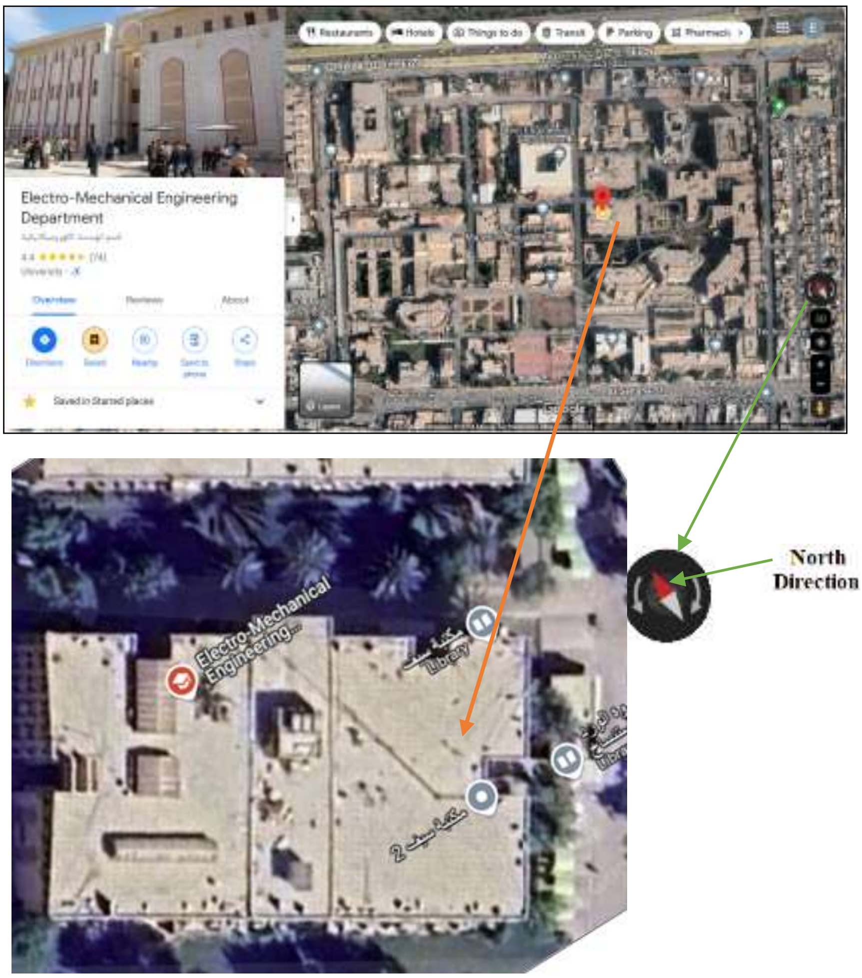

Figure 2. The location and the front facade of the electromechanical engineering department building

2.2 Lighting system

The power consumption values for both the LED light and the tungsten light were calculated depending on the current values that were measured using a multimeter device. Moreover, the light intensity of both lights was measured by using a light meter device. The photo of the LED light and the measurement devices are shown in Figure 3. The specifications of the light meter device and multimeter device are listed in Table 2, and the measurements of the current and light intensity, as well as the power consumption values, are listed in Table 3.

Figure 3. LED light bulb with measurement devices building

Table 2. Specifications of measuring devices

Type of Device	Accuracy	Range
Dual-Display Traceable Light Meter	±4.5% of full-scale reading	0 to 50,000 Lux
Multimeter (Senit Vc 890D)	±2% of full-scale reading	2 mA to 10 A

Table 3. Light intensity, current and power consumption of LED and conventional lights

Lighting System Type	Light Intensity (LUX)	Current Consumption (A)	Power Consumption (W)
Conventional	260	0.454	99.9
LED	411	0.03	6.6

2.3 Ventilating system

A ceiling fan with hidden blades (the new ventilating system) was selected to compare its performance with the old conventional ceiling fan that has visible blades (old conventional ventilating system), as shown in Figure 4. The current consumption values from the conventional and the proposed ventilating systems were measured for different speeds by using a multimeter device, and Table 4 shows the values of these measurements.

Figure 4. Conventional and proposed ceiling fan

Table 4. Measurements of current consumption for conventional and proposed fan types

Fan Type	Current Consumption at First Speed	Current Consumption at Second Speed	Current Consumption at Third Speed
Conventional type	0.1	0.27	0.29
Proposed type	0.08	0.2	0.21

2.4 Using secondary roofs and specifying their thermal properties

Gypsum plates with a thickness of 0.01 m and a thermal conductivity of 0.295 W/m.°C were used as a secondary roof in the building's rooms to reduce their volume and insulate them thermally from the upper side. The volumes of all rooms before and after adding the secondary roofs are listed in Table 5.

Table 5. Measurements of rooms' volume before and after using the secondary roof

Type of Room	Volume Before (m^3)	Volume After (m^3)
Classroom hall No.1	864	576
Classroom hall No.2	864	576
Classroom hall No.3	634.5	364.5
Classroom hall No.4	634.5	364.5
Classroom hall No.5	634.5	364.5
Classroom hall No.6	634.5	364.5
Classroom hall No.7	684	576
Classroom hall No.8	684	576
Seminars & Conferences Hall	945	525
Seminars hall	675	450
Office of head department	302.5	201.6

2.5 Theoretical calculations

The details of the lights and fan numbers that were used in the theoretical calculations have been listed in Table 6.

Table 6. The number of lights and fans in the building's rooms

Type of Room	Number of Lights	Number of Fans
Classroom hall No.1	35	16
Classroom hall No.2	35	12
Classroom hall No.3	28	15
Classroom hall No.4	13	15
Classroom hall No.5	20	15
Classroom hall No.6	28	16
Classroom hall No.7	35	16
Classroom hall No.8	35	20
Seminars & Conferences Hall	38	-
Seminars hall	30	20
Office of head department	17	-
Office of the Department Council	8	-

The electric power consumption from lighting and ventilating systems, as well as the cooling load due to the lighting system and the presence of the secondary roofs, can be calculated as follows:

The electric power consumption (EPC_{light}) from the lighting system can be calculated by the following equation [29, 30]:

$$EPC_{light} = P \times t/100 \quad (1)$$

$$P = V \times I \times N_1 \quad (2)$$

The percentage increase in light intensity (PLI) can be found by using the following equation:

$$PLI = \frac{L_{LED\ lights} - L_{Old\ lights}}{L_{LED\ lights}} \quad (3)$$

The electric power consumption (EPC_{fan}) from the ventilating system can be calculated by the following equation [31]:

$$EPC_{Fan} = P \times t/1000 \quad (4)$$

$$P = V \times I \times N_2 \quad (5)$$

The cooling load due to utilizing the lighting system can be calculated from the following equation [32]:

$$Q_{cooling,\ light} = W \times FUT \times FSA \times (CLF) \times N_1 \quad (6)$$

where, W is the total Watts from the lighting system, FUT is the lighting use factor, which is assumed to be unity because the types of spaces are offices and classrooms, FSA is the special ballast allowance factor assumed to be unity because of the lack of ballast in the lighting type used in the study, and CLF is the cooling load factor that is assumed to be 0.98.

One of the present research's objectives is to show the effect of the presence of secondary roofs on reducing the cooling load through the ceiling. Therefore, in cooling load calculations, only the cooling load through the building's roofs was considered, and the other thermal loads due to walls, people, etc. were neglected.

The cooling load through the roof before and after using the secondary roofs can be calculated as follows [33, 34]:

$$Q_{cooling} = u_r . A_r . CLTD_r \quad (7)$$

The overall heat transfer coefficient u_r can be calculated by calculating the thermal resistances of roof components as follows:

$$u_r = 1/(\frac{1}{f_{in}} + \frac{x_a}{k_a} + \frac{x_b}{k_b} + \cdots + \frac{x_n}{k_n} + \frac{1}{f_{ex}}) \quad (8)$$

where, x_a, x_b, and x_n represent the thickness of roof layers, (k_a, k_b, and k_n) represent the thermal conductivity of structural materials for the roof. While (f_{in} and f_{ex}) represent the thermal resistance of air layers on both sides of the roof (see Table 7).

The ($CLTD_r$) can be determined by the external design temperature and the difference in daily change of the external temperature, the rate of daily change is divided into three rates [35]:

- Little change rate (the difference less than 9°C).
- Medium change rate (the difference from 9°C to 14°C).
- High change rate (the difference of more than 14°C).

The values of ($CLTD_r$) were selected depending on reference [36] and were listed in Table 8.

Table 7. Components of the building's roof [22]

Layer Type	Thickness (m)	Thermal Conductivity (W/m.°C)
External air layer	-	-
Concrete Tile	0.05	1.785
A mixture of cement and sand	0.02	0.721
Cork	0.05	0.045
Soil	0.05	0.788
Asbestos	0.0625	0.115
Concrete	0.15	1.775
Plaster	0.02	0.81
Internal air layer	-	-

Table 8. $CLTD_r$ values

Direction	$CLTD_r$ Value (°C)
North (N)	17
Northeast (NE)	19
East (E)	24
Southeast (SE)	24
South (S)	21
Southwest (SW)	29
West (W)	31
Northwest (NW)	25

The annual costs before and after applying the proposed strategies have been calculated by multiplying the electricity tariff cost, which is about USD 0.013 per kWh, by the annual energy consumption, as follows [37]:

$$Annual\ cost = Electricity\ tariff\ cost \times anuall\ energy\ consumption \quad (9)$$

3. RESULTS AND DISCUSSION

The electric power consumption of lighting systems (EPC_{light}) for one academic year is shown in Figure 5. A dramatic reduction in electric power consumption can be observed when replacing the old system with the LED lighting system. The LED lighting system saves about 93.3% of the electric power consumed by the conventional system, where the total saving in electrical power for all building rooms in one academic year is 28840.9 kWh.

Figure 6 shows the comparison in terms of light intensity between the old conventional lighting system and the proposed LED lighting system. As shown in this figure, the new lighting system offers a light intensity higher than the conventional system (PLI) by about 34.8%.

Figure 7 shows the electric power consumption (EPC_{fan}) of the ventilating systems. The comparison covered one academic year and adopted three different fan speeds. It is found that the conventional fan system consumes electrical power more than the economical fan by about 735 kWh (24%) at the first speed, 2143.6 kWh (26%) at the second speed, and 2450 kWh (27.5%) at the third speed.

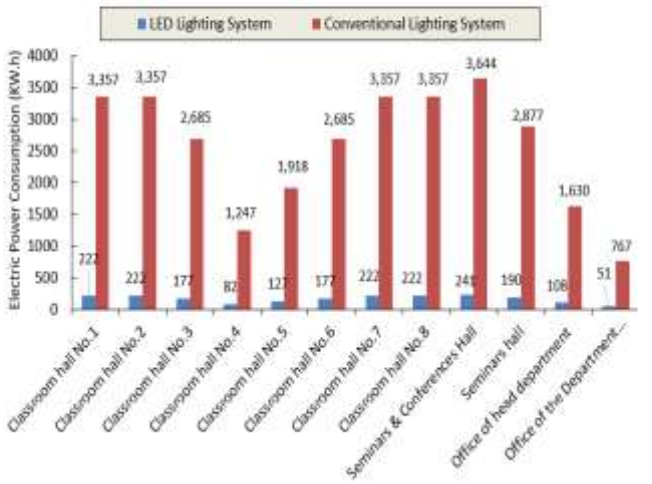

Figure 5. Electric power consumption of lighting systems for one academic year

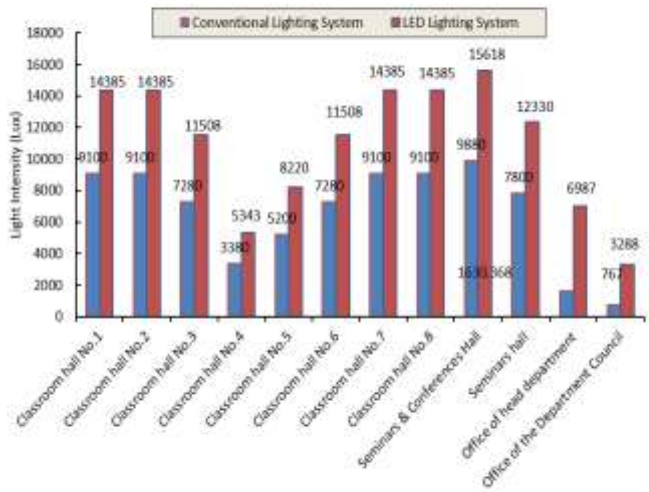

Figure 6. Comparison in terms of light intensity for lighting systems

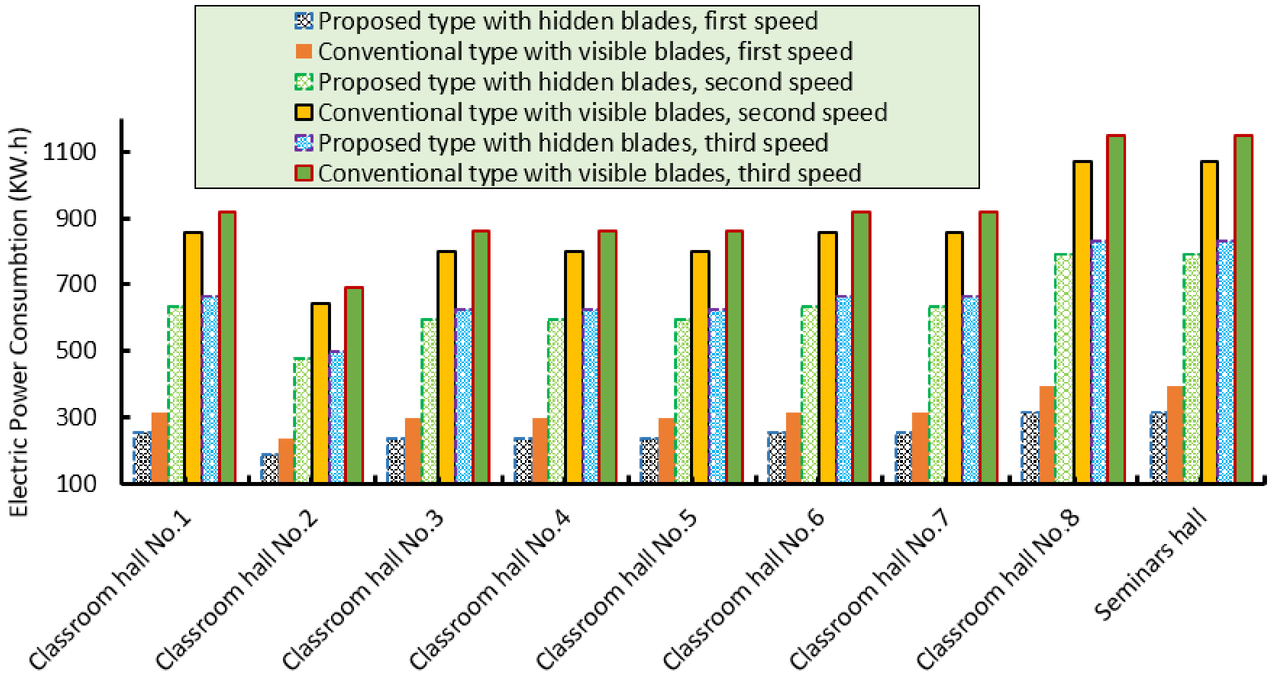

Figure 7. Comparison between fan systems for one academic year

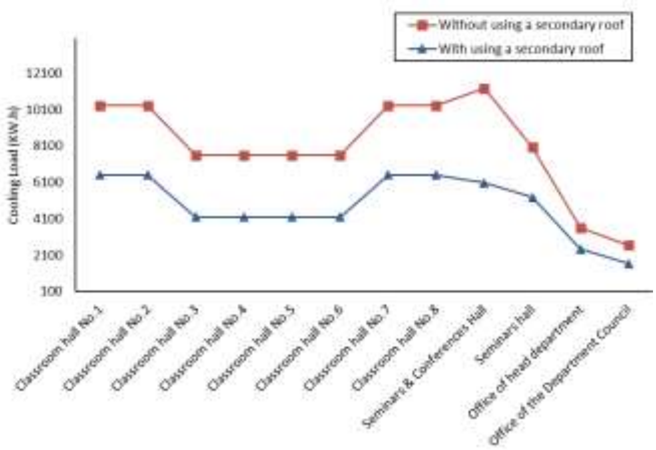

Figure 8. Cooling load before and after using secondary roofs for one academic year

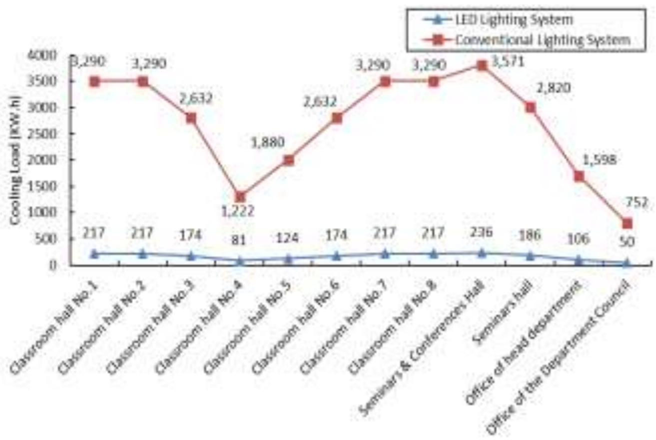

Figure 9. Saving in cooling load/ hour after using an LED lighting system for one academic year

Figure 8 shows the effect of using the secondary roofs on the cooling load. It can be observed that when adding the secondary roofs, the cooling load reduces due to the reduction in the room's volume and due to reducing the amount of heat that transfers from the upper side through the ceiling. The amount of cooling load that has been saved for one academic year due to using the secondary roofs in study halls No. 1, 2, 7, and 8 for one working day was 4284.8 TR (15069.2 kWh) while reaching 3795.2 TR (13347.3 kWh) for study halls (No. 3, 4, 5, and 6), and regarding the rest of the rooms, the amount of saving in cooling load was 2814.2 TR (9897.2 kWh). The total saving in cooling load for all building spaces due to utilizing the secondary roofs was 10894.2TR (38313.7 kWh).

In addition, as shown in Figure 9, the amount of cooling load saved from using the LED lighting system was 28264.1 kWh. Therefore, the total cooling load that can be saved due to applying the strategies is 66577.8 kWh, as observed in Figure 10.

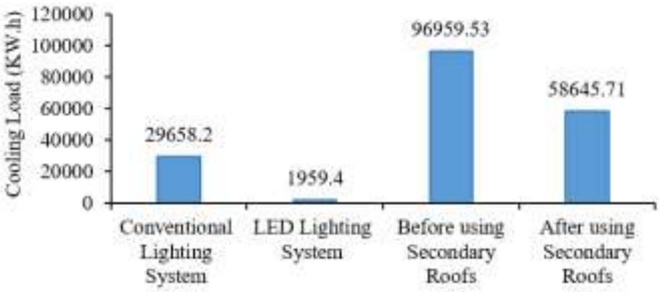

Figure 10. Cooling load needed in one academic year

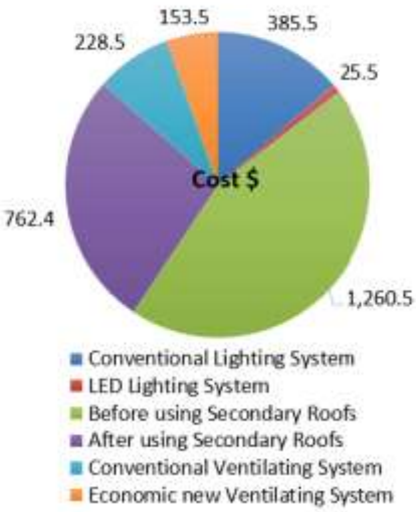

Figure 11. The cost in one academic year

Figure 11 shows the annual energy cost before and after applying the proposed strategies. By looking at this figure, it can be observed that the proposed LED lighting system contributes to saving about 93% of the annual cost of lighting the building. In addition, replacing the conventional ventilating system with the new economic system contributes to reducing the annual cost by about 32.8%. Moreover, the cost of the building's air-conditioning requirements has been reduced by about 39.5% when utilizing the secondary roofs. In addition, Table 9 shows the economic feasibility of using the techniques used in this study, and based on this table, it can be seen that the reduction in the purchase cost of the ventilation system was 15.4%, while it reached 50% in the case of replacing the conventional lighting system with the LED system.

Table 9. The economic feasibility of using the proposed strategies

Type	The Purchase Cost of One Piece (IQD)*	Cost % of Total Number of Used Pieces (IQD)*	Percentage Reduction in the Cost of Purchase %
Conventional Lighting bulbs	1,000	322,000	50
LED Bulbs	500	161,000	
Conventional Fan	60,000	8,700,000	15.4
Proposed Fan	52,000	7,540,000	

*The purchase cost was estimated by Iraqi Dinar (IQD) according to the local markets.

4. CONCLUSION

In this study, different strategies for energy consumption management in Iraqi academic facilities were evaluated. These strategies included replacing the existing conventional lighting and ventilation systems with newer systems that are based on energy-saving equipment and reducing the building's space by installing secondary ceilings to reduce the air-conditioning system's requirements. The study outcomes can be summarized in the following brief points:

1. Replacing the conventional lighting system with an LED lighting system saves about 93.3% of the electrical power that is consumed in one academic year.

The percentage of increasing light intensity after replacing the lighting system is 34.8%. Thus, it can be claimed that the feasibility of using LED lights for lighting a space is better than the conventional lighting system.

2. Using a proposed fan system instead of the old conventional fan system can decrease the electric power consumption for one working day by about 24%-27.5%, depending on fan speed.
3. Using secondary roofs reduces the building's volume by about 34.6%. Therefore, it can save 10894.2 TR (38313.7 kWh) of the total cooling load of the building for one academic year.
4. Using both LED lighting systems, an economical ventilating system, and secondary roofs contributes to saving about 93%, 32.8%, and 39.5%, respectively, of the annual cost.

For future research, it is possible to study the effect of using sustainable agriculture outside the walls and roofs on reducing the heat leaking into the building. In addition, studying the effect of using artificial intelligence techniques in energy management inside the building.

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NOMENCLATURE

A_r	roof area (m^2)
CLF	cooling load factor
$CLTD_r$	cooling load temperature difference (°C)
EPC_{light}	electric power consumption by the lighting system (W)
EPC_{fan}	electric power consumption by the ventilating system (W)
f_{in} & f_{ex}	thermal resistance of air layers on both sides of the roof.
FUT	lighting use factor, as appropriate
FSA	Special ballast allowance factor, as appropriate
I	current consumption (Amp.)
k_a, k_b, & k_n	Thermal conductivity of structural materials for the roof ($W/m^2.°C$)
$L_{LED\ light}$	light intensity of LED lighting system (LUX)
LED	light-emitting diode
$L_{Old\ light}$	light intensity of old lighting system (LUX)
N_1	number of lights
N_2	number of fans
PLI	percentage increase in light intensity.
P	power (W)
$Q_{cooling,\ roof}$	cooling load from the roof (W)
$Q_{cooling,\ light}$	cooling load due to utilizing the lighting system (W)
t	time period during which the power was consumed (Sec.)
u_r	overall heat transfer coefficient ($W/m^2.°C$)
V	voltage (Volt)
W	total watts from the lighting system (W)