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Energy Performance Assessment of a Non-domestic Service Building in Jordan

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Abstract

This work assessed the energy performance of a non-residential service building in Jordan. A comprehensive energy audit was conducted through which building systems were investigated including the building envelope, HVAC, and lighting systems. Multiple site surveys were conducted using standard audit instruments to record different operating conditions. Energy analysis, consumption trends, and system specifications were all examined, additionally, retrofit solutions were proposed to enhance the efficiency of each system. Results indicated that replacing all the single glazed windows with double-glazed thermally broken windows could yield a reduction in total energy consumption by 9%. Moreover, installing LED fixtures instead of the existing fluorescent fixtures can lower the total annual energy consumption by 4%. Also, in this particular building, separating the building's first floor balcony terrace from the ground floor can reduce the total annual energy consumption by 13%. Additionally, using all proposed retrofit solutions can reduce the building total annual energy consumption by more than 33%.

Keywords: *Energy performance assessment, Energy efficiency, Energy audit, Non-domestic service buildings, Jordan.*

1. Introduction

The continuous use of fossil fuels over the last 100 years had detrimental environmental impacts that manifested itself in global warming among other consequences [1]. In addition, the ever-diminishing fossil fuel sources caused a giant leap in the interest in assessing the energy performance and efficiency in buildings. As such, many studies worldwide addressed the impact of various retrofit measures on energy consumption in buildings [2-4]. Findings showed that thermal improvements in buildings can result in substantial energy savings in excess of 40% [5, 6], as well as a reduction in cooling loads of up to 80% [7]. Other studies involved implementing energy audits for existing commercial office buildings and resulted in an average energy utilization index (EUI) of about 235 kWh/m^2/year [8]. Susorova et al. [9] examined commercial office buildings under six climate zones in the USA and showed that fenestration improvements can yield up to 14% reduction in building total energy consumption in hot climates.

Jordan, like many other developing countries, imports more than 97% of its energy needs[10], leading to vital socio-economic consequences [11]. Also, Jordan's primary energy demand is forecast to grow by 62% by the year 2025 [12]. In response, a national energy efficiency strategy was launched in 2005 that included a wide range of energy efficiency measures [13, 14]. This strategy marked the first systematic governmental and, to a much less extent, research community's interest in the energy issue in the country.

Several local sporadic research efforts tackled energy efficiency and building energy performance in Jordan. Overall, most studies investigated the feasibility of incorporating energy efficient measures to various types of existing buildings [15-21]. Alzoubi,and Al-Zoubi [22] conducted a simulation study on the impact of different shading devices and configurations on daylight quality and building energy performance. Results showed that internal luminance can be maximized with minimum solar heat gain by utilizing vertical shading devices. Also, energy and exergy utilization in Jordan were investigated by Al-Ghandoor [23] who utilized the end-use models to perform the required energy analysis. Al-Ghandoor found that Jordan's energy efficiency amounted to about 48%, and energy efficiency to 23% and further reported that the industrial sector is the most energy efficient amongst others [23].

Based on our literature search, it was evident that, compared to other world regions, there is a serious lack in systematic studies on energy performance and efficiency in buildings in Jordan and the region. Therefore, this work was initiated to assess, in a comprehensive and integrated manner, energy performance of the building of Irbid Chamber of Commerce through an extensive energy audit

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and investigate implementing an upgrade to existing systems to assess the potential enhancement of the building's energy efficiency and performance.

2. Materials and Methods

This study was conducted at the building of the Chamber of Commerce (Figure 1) of the City of Irbid, located in the Northwestern part of the country. The exact geographical location of the building is 32.5441° N, 35.8596° E.

Figure 1: The building of Irbid Chamber of Commerce (ICC).

2.1. Building Information

Detailed energy assessments were conducted on the building envelope, HVAC system, and the lighting system as they make up almost the total energy consumption in the building.

As the building layout sketches were initially not available, they were reproduced using Pro/ENGINEER CAD (Figure 2). Wall orientations and fenestration components were recorded from true North using a smart phone accelerometer chip. Then, building information was gathered on major energy consuming devices, fenestrations, shading techniques, HVAC, existing abnormalities (viz., apparent leakages, broken lights), and occupant's attitude toward energy consumption. These notes formed the basis of the follow up extensive audit of the building.

The building was erected in 1996 and consists of an underground and ground floors, and three more levels. Its main entrance is facing southwest with a large tinted glass façade that has a vestibule entrance with two gates; internal and external that are about 2.0 m apart.

2.2. Instruments used

A measuring tape, Lux meter (Lutron LM-8010), temperature and humidity meter (Di-Log DL7102), and an IR thermometer (Raytek Rayngerr MX 4KM98) were used.

2.3. Systems considered and approaches used

2.3.1. The building envelope.

The parameters considered here were wall and window dimensions and orientation along with the specifications of envelope component. For windows, the overall heat transfer coefficient (U), solar heat gain coefficient (SHGC), visible transmittances (VT), and air leakage were examined. For walls, types of layers, their thicknesses, thermal conductivities and resistances, and overall heat transfer coefficient (U) were recorded. Data on thermal properties of some envelope components were obtained from local codes.

2.3.2. The HVAC system.

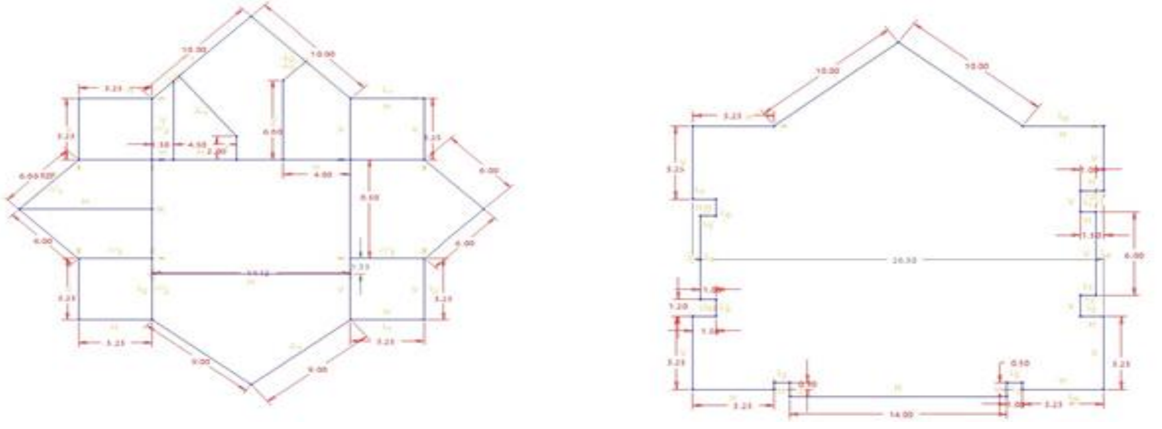
The building heating system consists of a diesel-fired boiler (RIELLO type - RL70), while the cooling system consists of a 150-kW electric water-cooled chiller (BITZER type). The assessment of the HVAC system started with air distribution units.

Temperatures of supply air, room air temperature, and radiators were recorded.

Energy consumption of the heating system was estimated from the equation **[24]**:

$$Qh = \left(UA_{glaze} + UA_{window} + UA_{frame}\right) \cdot \Delta T + \frac{1}{2}\, V\, C_p\, \rho\, \Delta T \qquad (1)$$

where, U is the overall heat loss coefficient, A is the total floor area, ΔT is temperature difference, V is the floor volume, C_p is the specific heat of air, and ρ is air density. Cooling energy consumption was calculated using the formula [24, 25]



(a) First floor (b) Second and third floors

Figure 2:. The general layout of the building of Irbid Chamber of Commerce.

$$Qc = \left[\left(UA_{glaze} + UA_{window} + UA_{frame}\right) . \Delta T\,\right] + \left[\frac{1}{2}\, V\, C_p\, \rho\, \Delta T\right] + [N\,.\,M] + \left[A_{glaze}\,.\,SHGC\,.\;G\,.\,cos\theta\,\right] \qquad (2)$$

where N is the number of people per floor, SHGC is the solar heat gain coefficient, G is the solar insolation (assumed 800 W/m^2), and θ is the solar altitude angle (approx. 83^o altitude for local summer), M is the metabolism heat generation (100 W per person) [25]. The second term in Equations 1 and 2 is the air change per hour (assumed 0.5 to account for infiltration) [25].

Finally, additional heating/cooling loads due to human-related factors such as energy misconducts were estimated using the following equation which is an alteration of the air change method infiltration formula [26]:

$$Q_{hlosses} = hr * P\% * \rho\, Q\, C_p \Delta T \qquad (3)$$

where hr is the working hours per year, P% is the percent of misconducts that represents the percentage of the working hours during which human related losses are imposed (estimated around 10% of the working day), and Q volume flow rate, assumed to be about 5 m^3 per hour for the building [26]. In this work, the temperature difference between indoor and outdoor were assumed to be 20 ^{o}C for winter and 14 ^{o}C for summer.

2.3.3. The lighting system.

Notes were taken on fixture specification, count, and distribution, in addition to lux data. Also, Luminaire Dirt Depreciation (LDD) and Lamp Lumen Depreciation (LLD) data were considered. The visual comfort probability (VCP) was assessed by performing a survey on building occupants in terms of lighting glare, and work environment lighting quality while the Color Rendering Index (CRI) was determined from the datasheets.

Finally, internal shading in each room was accounted for.

2.3.4. Appliances.

These included mostly computers and printers. It was assumed that computers operate 5 hours a day; the mean loading is 75%, and 25% for computers and printers, respectively.

3. Results and Discussion

3.1. Building Envelope

The gross area of the building walls was about 1370 m^2. The walls consisted of several layers including limestone, insulation, hollow block, and plaster. Table 1 outlines the specifications of wall layers (thermal conductivity, k, and overall heat transfer coefficient, U).

Table 1: Specifications of wall components.

Layer	Thickness	Thermal conductivity	Thermal resistance	U-factor
	m	W/m^2.K	m^{2}K/W	W/m^2.K
Limestone	0.3	0.95	0.3158	0.6*
Insulation	0.05	0.04	1.25	
Hollow-Block	0.1	1	0.1	
Plaster	0.02	1.4	0.0143	

*Makes about 100% of the wall's total U-value.

The gross window area in the building was about 490 m^2. All windows were single glazed (U of 2.1 W/ m^2.K) with aluminum frames (U of 2.4 W/ m^2.K) and overall U factor of 4.5 W/ m^2.K. South-facing windows in the ground and first floors, although tinted, they admit substantial amount of daylight due to their large areas. In contrast, north-facing windows can better reduce lighting load by benefiting from daylight. However, these windows were small and heavily shaded all day. As such, folding the shades can enable more access to ambient day lighting.

3.2. Heating and cooling loads

Figure 3 shows that the peak heat load was about 18 MWh and that heating load in December 2016 was only 10% of the corresponding load in 2015 due to utilizing the PV in the heating mode. The mean heating load in 2016 was about 60% of that in 2015, which was due to utilizing the PV system. Figure 3 also compares the "ideal" heat load (zero losses), with the actual measured data indicating that losses impose a 30% increase in heating load.

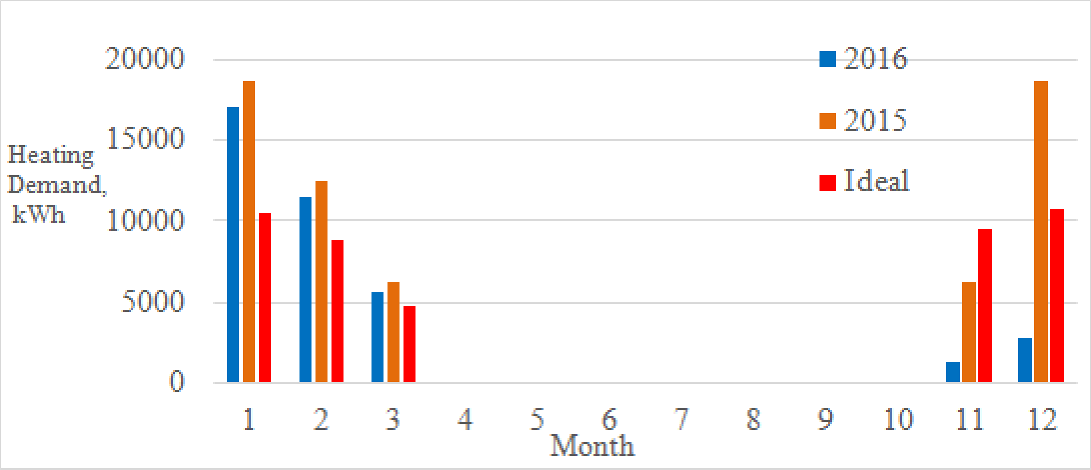


Figure 3: Actual and ideal monthly heating loads for the ICC building for 2015 and 2016.

Figure 4 shows that cooling load peaks (12 MWh) in August and cooling loads were similar for 2015 and 2016 due to similar weather conditions. Figure 4 also reveals that the actual cooling load would be 10% higher than the ideal goal as there had been no infiltration or heat gains.

3.3. Lighting and appliance loads

Lighting specifications in each floor are outlined in Table 2.

Lighting types used were CFL, F15T8, and LED with several fixtures that were either broken, at the end of their life cycle, or with high dirt depreciation. As for glare, the survey results revealed a 70% rate of satisfaction among employees. (IES). Table 3 outlines the performance of existing lighting in the building relative to recommended values Illuminating Engineering Society IES [27].

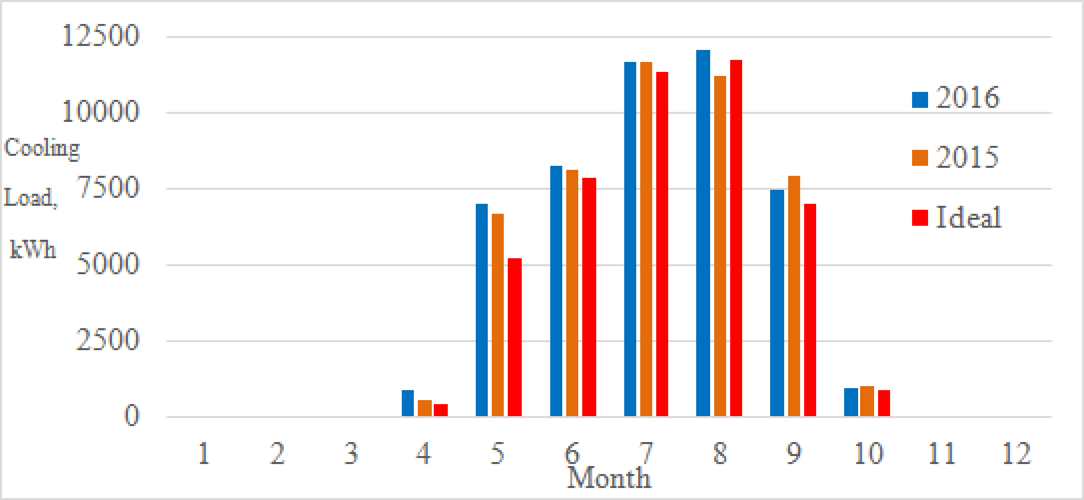


Figure 4: Actual and ideal monthly cooling loads for the ICC building for 2015 and 2016

Table 2: General specifications of existing lighting.

Floor	Lighting type	Number of fixtures	Wattage	Total power peak load	Lighting peak load
Ground	CFL	9	24	576 W	11892 W
	F15T8	6 (4×)	15		
First	CFL	4	24	3760 W	
	F15T8	29 (4×)	15		
	LED	52	37		
Second	CFL	20	24	2276 W	
	F15T8	25 (4×)	15		
	LED	8	37		
Third	CFL	10	24	5280 W	
	F15T8	84 (4×)	15		

Table 3: Performance indices of existing buildings and nominal values.

Performance index	Lux	Uniformity	Glare	CRI
Actual values Nominal values	Offices and labs: 350	insufficient light distribution	Mean VCP: 70%	80+
	500	Uniform on work-plane	VCP: 80+	Excellent: 90+

As far as appliances are concerned, relevant data showed that, at the time of this study, the building had 56 computer units rated at 130 W and 22 printers rated at 30 W. This made the average daily energy consumption by appliances around 28.6 kWh.

3.4. Electricity and diesel consumption

Figure 5 shows electricity consumption (kWh) for the years 2015 and 2016. It should be noted that the difference in consumption between the two years is due to the fact that there is an underground floor that was vacant in 2015, but has been rented to a medical center in June 2016. The medical center was factored out from assessment. Electric load in winter was substantially lower than that in summer because heating was performed by a diesel-fired boiler.

The peak, average, and base electricity loads for the year 2016 are depicted in Figure 6 which shows a peak load in August at around 16 MWh which is due to high electric cooling loads. Moreover, the dip in Figure 6 around September is ascribed to the installation of a 50-kW PV system that carries part of the cooling/heating load via an integrated boiler and absorption cycles. The average electricity load was 9.5 MWh while the base load was 3.2 MWh.

Figure 7 shows that diesel consumption was maximum in January where heating load was maximum, whereas a significantly lower diesel consumption in November and

December of 2016 was noted, which is attributed to using the PV system in heating mode. As evident from Figure 7, the solar system contribution is vividly evident when comparing December 2015 to 2016 where diesel consumption was reduced by 3.65 m^3.

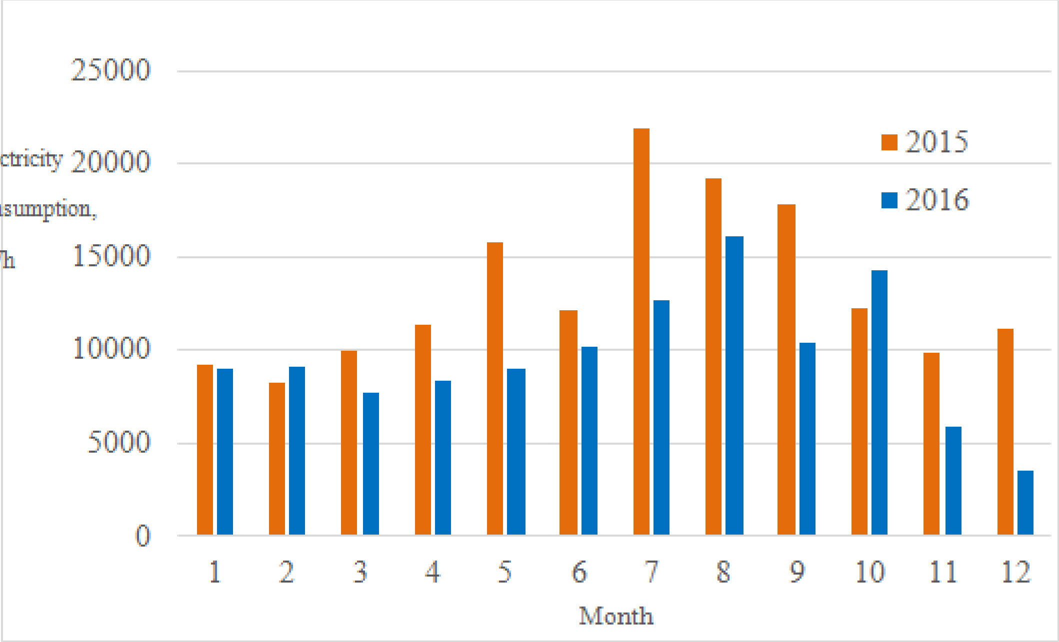


Figure 5: Monthly electricity consumption for the ICC building for 2015 and 2016.

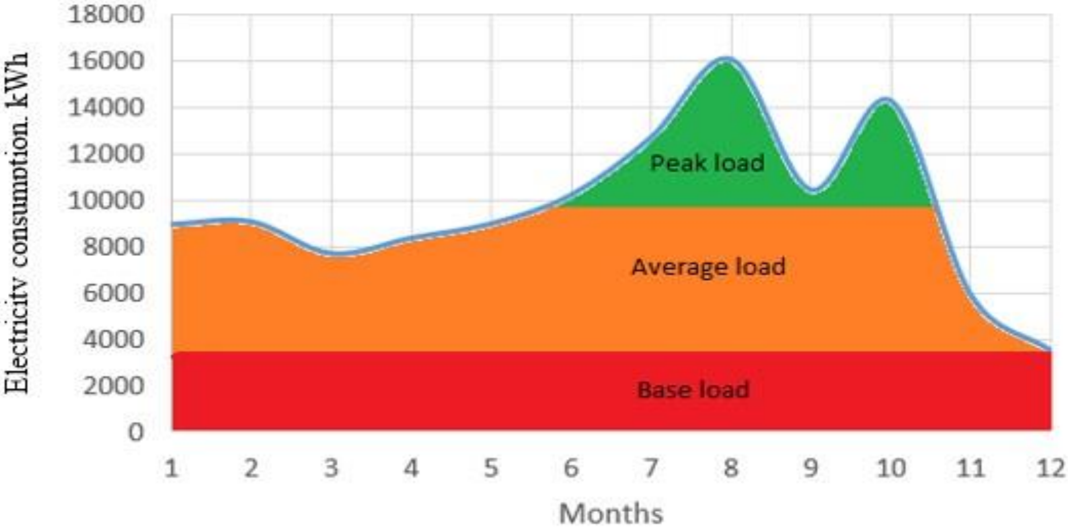


Figure 6: Peak, average, and base loads for the ICC building for 2016.

3.5. Building energy performance

Table 4 outlines electricity and diesel consumption for 2015 and 2016. Based on carbon emission data by electricity generating facilities in Jordan, 724 g of CO_2 are emitted per kWh of electricity [28], compared to about 277 g CO_2/kWh of energy generated by diesel fuel [29].

The annual heating load is higher than the cooling load, which is a consequence of heating degree days, HDD, and cooling degree days, CDD, which are, respectively, 2190 and 660 for the year 2016 [30].

3.6. Energy misconducts

Misconducts included such practices as setting heating thermostat at excessively high values. In contrast to a comfort heating temperature of 27 °C, temperatures of airflow in some offices were 46 °C. Moreover, it was noted that leaving the doors open to the unconditioned staircase which is open to the whole building and adjacent to the building envelope across four floors is common practice. Both misconducts caused substantial conditioning energy losses.

3.7. Proposed energy saving measures and their potential impacts

Based on the findings, major proposed measures involve switching to double-glazed and LED lights, avoiding excessive heat loss, dealing with energy misconducts and conducting awareness campaigns. The potential impact of the individual and all proposed measures are shown in Figure 8 which readily shows that implementing all proposed measures can yield up to 33% reduction in annual energy consumption.

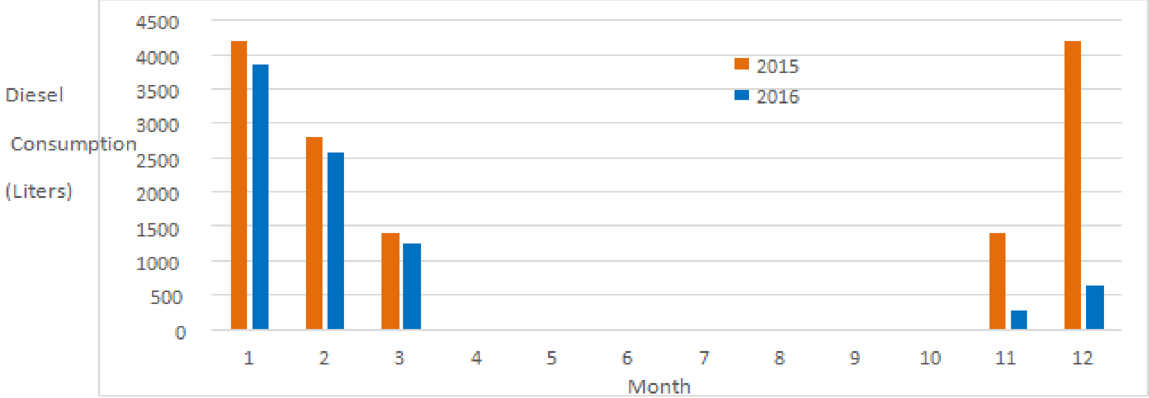


Figure 7: Annual diesel consumption for the ICC building in 2015 and 2016.

Table 4: outlines electricity and diesel consumption for 2015 and 2016.

Year	Energy Source	Total Consumption		Annual Cost	Consumption Index	Emissions
		(kWh)	(GJ)	JD	MJ/m^2	(tCO$_2$-e)
2015	Electricity	159013	572.45	39172	217.66	115.13
	Diesel		548.8	4855	208.67	42.26
	Total		549.37		426.33	157.39
2016	Electricity	116138	418	28766	158.94	84.08
	Diesel		671.58	5792	255.35	51.71
	Total		671.98		414.29	135.79

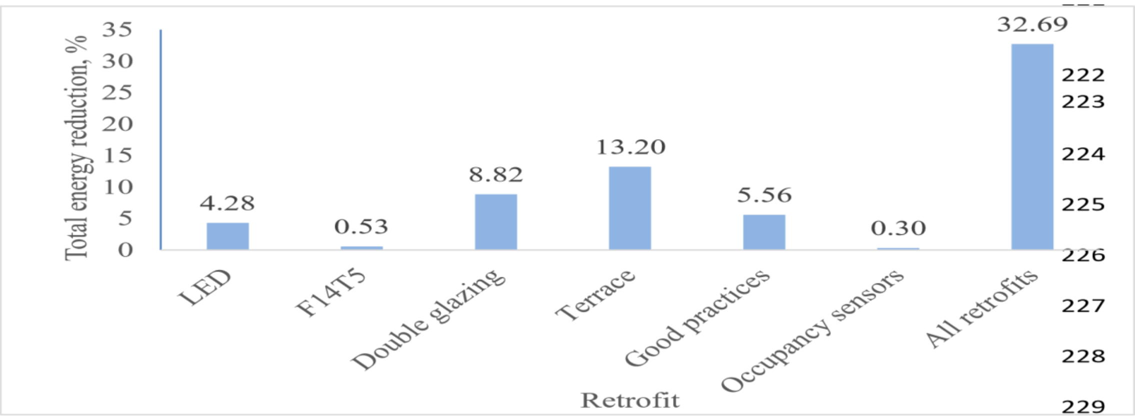


Figure 8: Existing system and proposed retrofit annual total energy consumption.

4. Conclusion

Based on the findings of this study, it may be concluded that in a country like Jordan that relies heavily on imported energy, a substantial potential does exist not only for reducing energy consumption, but also for simultaneously improving the level of human comfort in service buildings. Also, in such buildings, the envelope, HVAC, and lighting systems make up almost the total energy consumption and thus energy management efforts should focus on them. In addition, this work indicated that a reduction of 33% is achievable by implementing common retrofits to the existing building systems considered here. Also, this study revealed that, at the national level, there is a serious deficiency in energy audit efforts and hence there is a genuine need for systematic awareness campaigns and audit effort in this respect. Finally, implementing renewable energy projects, particularly, PV systems, can make substantial savings in energy consumption in buildings. Therefore, national incentive programs to this end should be re-examined and expanded.

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