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Energy and Water Saving Potential in Commercial Buildings: A Retrofit Case Study

Wahhaj Ahmed [1,*], Ayman Alazazmeh [2] and Muhammad Asif [1,3]

1 Architectural Engineering Department, King Fahd University of Petroleum and Minerals, P.O. Box 855, Dhahran 31261, Saudi Arabia
2 Mechanical Engineering Department, King Fahd University of Petroleum and Minerals, P.O. Box 279, Dhahran 31261, Saudi Arabia
3 Center for Renewable Energy and Power Systems, King Fahd University of Petroleum and Minerals, P.O. Box 855, Dhahran 31261, Saudi Arabia
* Correspondence: wahhaj156@gmail.com; Tel.: +966-13-860-2966

Abstract: The global building sector has great potential for energy savings. Retrofitting of existing buildings can effectively improve their energy and environmental sustainability. However, retrofitting is a complex task and requires proper Measurement & Verification (M&V) to validate the process for various building types and locations. Such M&V studies for commercial buildings in the studied region are missing and a critical gap exists. This paper addresses this gap by discussing the effectiveness of retrofit energy and water efficiency measures implemented in a commercial building in Saudi Arabia. At first, a thorough energy audit is conducted and then five Energy Efficiency Measures (EEMs) and a water conservation measure is implemented. A post-retrofit M&V exercise is conducted to measure and validate the savings along with respective economic benefits. The results indicate that the implemented EEMs reduced the building's annual energy consumption by 27%. The overall compound payback period for the investments is found to be six years. The study successfully validates the energy and water savings achievable through retrofitting by presenting the first M&V case study of a post-retrofit commercial building in the country. Thus, it proves that implementation of EEMs and water saving measures are effective strategies to retrofit commercial buildings in the region.

Keywords: energy; retrofitting; M&V; water; conservation; energy efficiency

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1. Introduction

Energy and water consumption globally are constantly on the rise and will continue to be in the business-as-usual scenario. Global freshwater consumption has increased by six times in the past century [1] and according to the United Nations (UN) World Water Development Report (WWDR), the freshwater demand has continued to grow by 1% since the 1980s [2]. At this rate, more than half of the global population will suffer from some form of water scarcity at least one month per year [3]. The case is similar for the global energy consumption. According to the International Energy Agency (IEA), since the turn of the century, increases of around 40% and 30% have been recorded, in the global energy consumption and Carbon Dioxide (CO_2) emissions, respectively, [4,5]. These increments are expected to continue as the developing countries continue to grow.

Increasing rates of energy consumption and CO_2 emission contribute toward the acceleration of global warming, which is presently one of the most significant threats to societal existence. Because of global warming, the earth's temperature is constantly rising at an incremental rate and a global effort has been started to find and implement solutions to mitigate its effects. The buildings and construction sector is one of the biggest contributors to global warming and is responsible for almost half of the world's material consumption, around one-third of the total global energy consumption, and more than 30%

of the greenhouse gas emissions on the planet [6,7]. During the past 100 years, an increase of 2.5 °C has been observed in some places on earth [8], and according to some estimations, it is required to reduce the total CO_2 emissions in the buildings and construction sector by 77% to limit the worldwide temperature increase to 2 °C by 2050 [5,9]. Thus, the inevitable way forward for new construction is to focus on sustainability and for existing buildings is to focus on energy retrofitting to improve energy efficiency.

Fundamentally, the definition of energy retrofitting is to improve a building's components that directly or indirectly contribute toward its energy use [10]. In the developed nations, energy retrofitting of the existing unsustainable structures is one of the main concerns. Previous studies have presented that, to meet the energy conservation targets, countries around the world have successfully invested in and implemented energy retrofitting projects [11,12]. A positive response has been observed from such energy efficiency projects in the developed countries [4,13]. On the other hand, in the developing countries, energy retrofitting is not that mature and the rate of CO_2 emissions is increasing continuously and will reach its maximum amount after 10–20 years [14]. In such countries, preference is given to construct new sustainable buildings and energy retrofitting of the existing unsustainable buildings is considered impractical and is hindered by several barriers including financial barriers [15,16].

Saudi Arabia is one of the leading countries in the Middle East. Its building sector has a high energy and environmental footprint. This is evident by the fact that the per capita energy consumption in the country is three times higher than the global average [17]. The per capita CO_2 emissions in the country also presents a similar trend [18]. However, there is a significant possibility to curtail the energy and water consumption of buildings in the country through energy conservation and retrofitting [19,20]. Moreover, the transformation plan of the country in the form of Saudi Vision 2030 advocates for a sustainable society and indicates that energy retrofitting of the existing unsustainable buildings will play a key role in delivering this vision [21,22]. Therefore, the energy retrofitting of existing buildings in the country is a rising area of research and development and it is still in its premature stages.

Most of the existing energy retrofitting studies, regardless of the building type studied, are simulation-based studies [23]. In these studies, typical or atypical case studies are utilized to measure the energy saving potential using various energy simulation tools. Such studies present the energy saving potential in the country and can be used to develop energy retrofitting plans; however, they lack in presenting a measured and verified project. Studies presenting post-retrofit Measurement and Verification (M&V) are vital as they validate energy retrofitting in a particular region. Such a study is not present for Saudi Arabia and a critical gap exists.

Without post-retrofit M&V studies, the energy and water savings achievable by energy retrofitting is not validated and there will always be an element of doubt among stakeholders before considering energy retrofitting for their buildings. Hence, the aim of this study is to present a measured and verified case study of a retrofitted office building in Saudi Arabia. The study is structured as such: Section 2 discusses M&V in building retrofitting and in Section 3 a discussion with past studies of energy and water consumption scenarios in Saudi Arabia is presented. Furthermore, in Section 4 the methodology of the case study M&V is presented, Section 5 presents the results and discussion for the retrofitted case study M&V, and Section 6 includes the conclusions and avenues for potential future work.

2. Building Retrofit M&V

Building retrofit M&V can be broadly classified into pre- and post-retrofit M&V. Pre-retrofit M&V is the calibration and validation of the building energy model. It can be conducted by comparing the simulation data with the actual energy consumption of the building. Conversely, post-retrofit M&V is performed after the retrofitting of the building has been conducted. Both of these M&V methods can be carried out by implementing various established M&V protocols. The major M&V protocols are (International Performance

Measurement and Verification Protocol) IPMVP, (American Society of Heating, Refrigerating and Air Conditioning Engineers) ASHRAE Guidelines, and the M&V Guidelines for Measurement and Verification for Federal Energy Projects for energy performance measurements and verification of existing building's energy uses. One of the most widely used protocols is the IPMVP.

The IPMVP offers four different calculation options that can be used to perform M&V. The decision to select a particular option depends on whether the EEMs are analyzed separately or the whole-building retrofit is being performed [24–26]. The four calculation options are as following [27]:

- Option A: performed for assessing the proper installation when equipment is changed. Engineering calculations are used to calculate the savings.
- Option B: performed at the device or system level after the completion of the project. The method to calculate the savings is also by engineering calculations.
- Option C: performed at the whole-building level to determine the savings using the pre-retrofit and post-retrofit utility meters' data. The method to determine the savings range from simple comparison of the utility meters' data to regression analysis.
- Option D: performed when savings are determined through energy simulations. Energy simulation tools are used to calculate the savings.

Studies presenting the M&V of retrofitted buildings following any of the above-mentioned protocols are vital as they validate the energy retrofitting process in any given location. Globally, several studies have adopted and presented these options to perform the M&V for office buildings. For example, Kim et al. presented the Heating, Ventilation, and Air Conditioning (HVAC) commissioning of a newly built office building in South Korea [24]. In their study, the IPMVP option D was utilized to calibrate the energy model. Furthermore, another study presented the M&V of energy conservation measures on commercial-office towers in Canada using whole-building electricity data, a methodology similar to using IPMVP option C [28]. Similarly, another example for M&V of energy retrofitted office buildings in a hot–humid climate is presented by Shin et al. in their study [29]. In their study, one portion of an office building located in Texas was renovated and converted to a Net Zero Energy Building (NZEB) while the other portion was left un-renovated. The implemented EEMs including a more efficient HVAC system, energy efficient lighting system, and improving the building's envelope insulation. In addition, a rooftop 32,130Watt DC rooftop solar Photovoltaic (PV) system was also installed. The results indicate that the energy retrofitted office building consumes almost 50% less energy annually and the rooftop PV produces 50% more energy than what is required by the building. Similarly, a study in the tropical climate of Singapore analyzed the pre- and post-retrofit data from 56 office buildings [30]. The study highlighted that, on average, a reduction of about 20% in the energy consumption was achieved in the retrofitted office buildings.

In addition, post-retrofit M&V can also be performed by monitoring the performance using sensors. For example, Jones et al. [31] determined several EEMs by surveying the tenants and implemented these EEMs on five houses in South Wales. They conducted the M&V of the houses for a period of one year after the energy retrofitting process using sensors and their results show a reduction in CO_2 emissions of around 75% by the energy retrofitted houses. Similarly, Hens [32] retrofitted a house in England for energy conservation. The EEMs were implemented on the house and the results were measured using sensors over a period. Their results showed that the energy consumption in the house was reduced by 20%.

To summarize, M&V for energy retrofitting projects can be conducted either before the construction or afterwards and there are several established methods that can be used to conduct the M&V. As presented in this section, studies exist in the literature that utilize these methods and present the M&V of energy retrofitting case studies. However, no such study exists for the investigated region and case study building type used in this study. Therefore, for this study, the IPMVP option C was chosen as it fits the best within the scope of the study of assessing the whole-building energy use. In option C, the whole-building energy consumption data were used from the electricity and water meters to compare and calculate the savings of a retrofitted office building. The IPMVP option C has several benefits including the ability to analyze the building's energy use in a timely manner even if the detailed information about the building is not available [33]. Further details about the case study M&V analysis are furnished in Sections 4 and 5.

3. Energy and Water Consumption in Buildings in Saudi Arabia

The building sector in Saudi Arabia consumes disproportionally high amounts of energy. The disproportionally high amounts of energy consumption in buildings is because of the harsh arid climate of the country, inefficient buildings, subsidized electricity prices, rapid growth due to favorable economic conditions, and issues toward the implementation and enforcement of the energy conservation codes [34–36]. In addition, the excessive use of energy is also because of the user behavior in buildings [37]. The harsh climate of the country entails that there is a significant cooling demand in buildings and almost 65% of the energy consumed is by the HVAC system [38]. Despite this fact, more than 50% of the buildings in the country are not thermally insulated [39]. This contributes significantly to the energy consumption of buildings. However, as stated earlier, there is a huge prospect of reducing energy demand in existing buildings through energy retrofitting [20].

A brief literature review reveals numerous recent studies have demonstrated a significant possibility of reducing energy demand in residential buildings [40–43] and educational buildings [44] in the country by energy retrofitting. For example, a study by Ahmed W. and Asif M. identified several measures that could reduce the energy consumption of residential buildings by 60%. They implemented EEMs including increasing the cooling set point temperature, using energy efficient appliances, replacing conventional lights with more efficient lights, applying window shading, improve the glazing type, improving air tightness, installing a more efficient HVAC system, and adding envelope insulation [40]. In their study, they assessed a three-level energy retrofit plan for the country and identified that by deep retrofitting in level three, energy consumption in residential buildings can be reduced by up to 60%. However, the payback period for the initial investment is not attractive. Similar results are corroborated by another study by Krarti et al. [45]. They presented a detailed bottom-up analysis of energy retrofitting residential buildings in Saudi Arabia. They proposed similar EEMs including improving the HVAC system, changing light types, using control strategies, improving the envelope properties, and improving appliance energy efficiency. Their results highlighted the possibility of reducing energy demand in the residential sector of Saudi Arabia could be curtailed by 100,000 GWh/year through a level three investment of USD 207 billion.

In terms of water consumption, the Middle East is one of the driest regions in the world. Five of the Middle Eastern countries are amongst the top ten most water scarce countries in the world, with Kuwait holding the first position owing to an annual per capita freshwater supply of less than 10 m^3. With its inhabitants accounting for 4.4% of the global population, the Middle East has access to only 1.1% of the freshwater reserves on the planet [46]. Within the Middle East, the Arabian Peninsula is the most disadvantaged sub-region with only 1 percent of the renewable water resources for an area equivalent to 47 percent of the Middle East. The situation makes the Arabian Peninsula the driest region in the world [47]. In recent decades, it has seen a rapid increase in water demand because of population growth, infrastructure development, modernization, and urbanization. Contrary to this, water supply has remained relatively static resulting in a growing gap between the supply and the demand.

To fill the surging gap between demand and supply, the Middle Eastern countries in general and GCC countries in particular are resorting to not only over-abstraction but also to sea water desalination. In recent decades, these countries have heavily invested in desalination to such an extent that 70% of the world's desalination plants are based in the Middle East [46]. GCC countries alone house 60% of the world's total installed desalination capacity. Desalination is an energy intensive and financially expensive option, especially considering the highly subsidized tariff. The cost of seawater desalinating in GCC is reported to be as much as USD 2/m^3, with a selling price as low as 5% of the production cost [48,49].

In Saudi Arabia, the largest country in the Middle East, the per capita renewable water supply standing at 94 m^3 in 2005 is forecasted to decrease to 56 m^3 by 2030 [50]. On the other hand, the water consumption pattern in the country is following a similar trend as the energy consumption is gradually increasing each year. The increasing water consumption in the country is evident by the fact that the per capita water consumption has increased by around 22% in the past decade alone [51]. The per capita water consumption rose from 227 L/year to 278 L/year and is said be the third highest globally [52]. Considering that the country is a water stressed nation depending mainly on desalination for its fresh water source, there is a dire need to reduce the water consumption in buildings. A study by Taleb, Hanan M., and Sharples, Steve implemented water saving measures on an apartment building and reduced the per capita water consumption significantly [53]. The water saving measures included low-flow tap aerators in the kitchen, low-flow tap aerators in the bathroom, low-flow showerheads, dual-flush cisterns, efficient washing machines, and a grey water system, which collects 90% of the bath and shower waste in order to supply to toilet cisterns. The results indicate that the water saving measures could reduce the consumption by up to 1,458,000 L of water in one year.

Generally, studies in the country highlight that energy retrofitting will certainly lead to significant energy consumption reductions in the buildings. Three significant gaps are identified that need to be addressed to advance the energy retrofitting research in the country. Only one study in 2007 identified that it is possible to reduce the energy consumption of an office building in the country by 36% [54]. Hence, a lack of studies concerning energy retrofitting of office buildings is observed. Secondly, there is a definitive lack of studies that present the M&V of energy retrofitted buildings in the region. Lastly, it is observed that very few studies report on the water conservation prospects in buildings. This study will address these three gaps.

4. Methodology

The methodology of the study is divided into four main steps (Figure 1). Firstly, the case study building is described. Next, the building's energy and water consumption data for one full year are presented. Additionally, an energy audit is conducted to collect sensor-based measurements that corroborates the one-year energy consumption from the energy meters and to identify the applicable EEMs. The third step is to select and present the EEMs and finally, in the last step, the cost analysis methods are presented. The steps are elaborated upon in Sections 4.1–4.4.

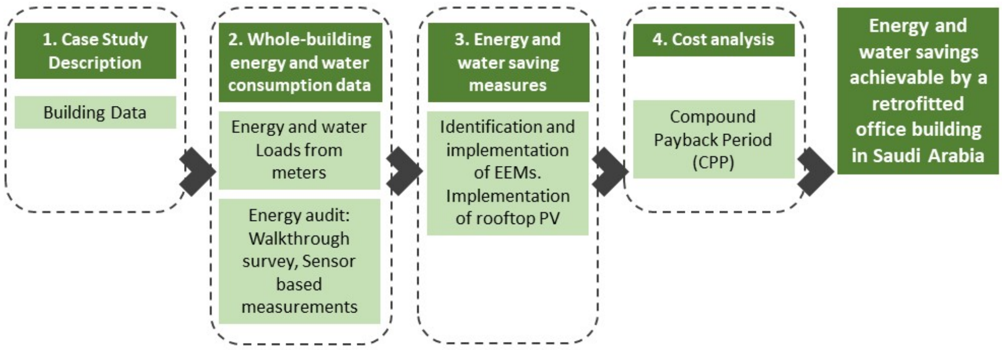

Figure 1. Methodology flowchart.

4.1. Case Study Description

The case study is an office building in the Eastern Province of Saudi Arabia. It was constructed in 2013 with a total built up area of 7500 m^2, consisting of 66 offices, four conference rooms, an auditorium, a mess hall, and a prayer hall. In terms of the orientation, the building is facing the Southwest (SW) direction. The window to wall ratio (WWR) is 25%. The typical floor plan of the building is shown in Figure 2 while Table 1 provides further details.

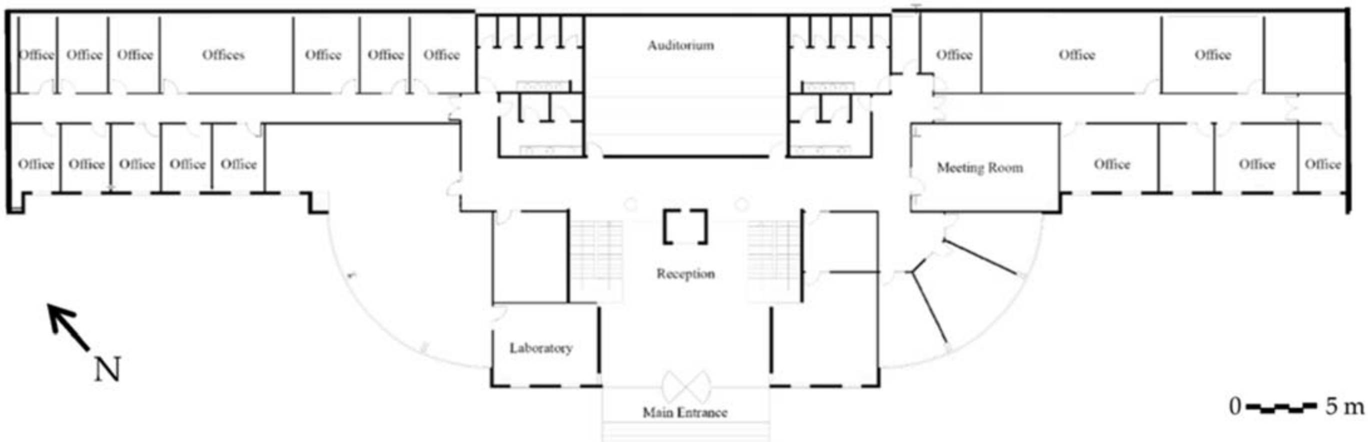

Figure 2. Typical floor plan of the investigated office building.

Table 1. Description of the case study building.

Parameter	Description
Orientation	Southwest (longest side)
Occupants	1000–1200
Floor height	Slab to Slab: 4.1 m
No. of floors	Three
Total built area	7500 m^2
Exterior walls	Brick face (4 inches)—Insulation (2 inches)—Concrete (4 inches) (U-Value = 0.51 W/m^2 K).
Interior walls	Double face double layer of 16 mm thick (fire-rated gypsum boards and moisture resistant for wet area) with thermal isolation and paint.
Roof	4-inch light weight Concrete Slab-$\frac{1}{2}$inch Roof (Asphalt roll)-8 Inch Reinforced Concrete Slab (1% steel), $\frac{1}{2}$-inch Cement Plaster-Paint (U-Value = 0.45 W/m^2 K)
Window to Wall (W–W) ratio	32.67%
Glazing	Double Glazing 13 mm air space
Shading	None
Air Conditioning (AC) type/description	Chilled water system (chillers, air-handling units, primary pumps, exhaust fan, and fan coil units)
AC set point	24 °C
Relative humidity	50%
Lighting	Mixed (Florescent Tube Light, High Pressure Sodium, and Halogen)
Infiltration	Infiltration controlled with inside positive pressure
Energy Use Index (EUI)	458.9 kWh/m^2/year

4.2. Energy and Water Consumption

The energy load of the building is dominated by the HVAC system. Other significant elements include office appliances, lighting, and exhaust fans. The HVAC system consists of four main components: chillers, primary pumps, Outdoor Air Units (OAUs), and Chilled Water Indoor Units (CHIUs). The building has its own chiller plants and generates chilled water using air-cooled chillers. There are three air-cooled chillers with a capacity of 170 TR each. The chilled water set point temperature is 7 °C throughout the year. There are two central OAUs of 20 kW each. The building uses 100% fresh new air for the HVAC systems and they are operational round the clock without any timing control. Important office services and appliances include elevators, office equipment such as computers and printing machines, and kitchen appliances. In terms of lighting, different types of bulbs such as Florescent Tube Light (FTL), High Pressure Sodium (HPS), and Halogens are used without any automatic control. There are eight exhaust fans of 1 kW capacity each to remove contaminated air from the building. The monthly energy consumption profile of the building is shown in Figure 3. Before the energy retrofitting, in 2018, the annual energy consumption was recorded to be 3,441,043 kWh. The Energy Use Index (EUI) was found to be 458.9 kWh/m^2/year. The annual electricity cost, based on the national rate of USD 0.048/kWh, amounted to USD 165,096. The highest consumption was recorded in the month of August and the lowest in January. This trend is understandable given that the HVAC loads considerably increase during the summer months as seen in the load distribution in Figure 3.

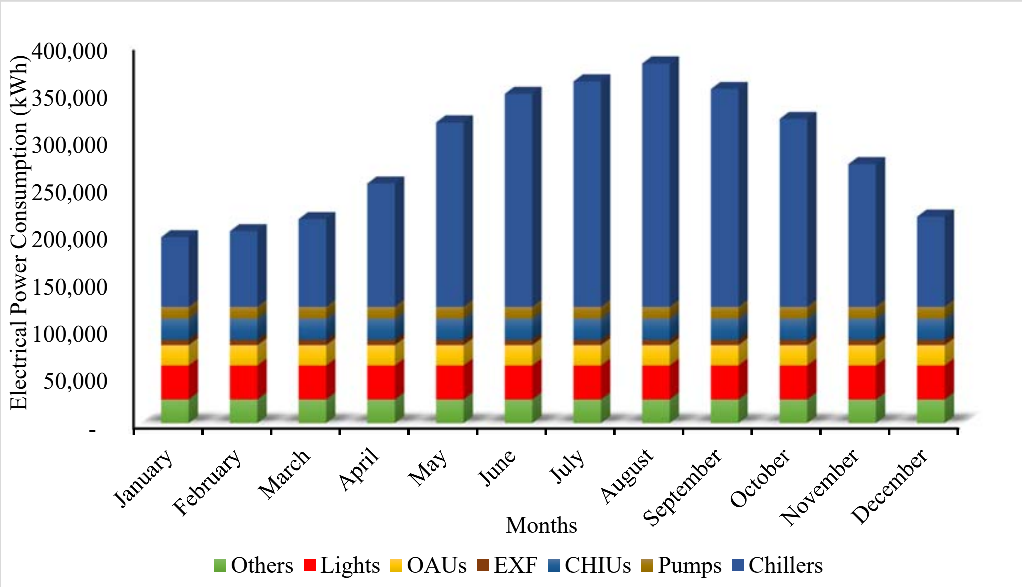

Figure 3. Monthly consumption profile and different load consumption for 2018.

4.2.1. Energy Audit

The energy audit is the starting point of an effective energy conservation and management exercise. It helps identify losses and areas to be improved through Energy Efficiency Measures (EEMs). Energy auditing, also termed as energy surveying and energy examination, is the process of inspecting, surveying, and analyzing energy consumption in a building to identify opportunities for energy saving without compromising the quality [55]. According to the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), an energy audit can be performed on three levels for commercial buildings [56,57]. The complexity, tasks, and accuracy vary in each of the three levels. For this study, an energy audit was performed, before energy retrofitting, from 10 April 2019 to 30 April 2019. The audit was conducted to meet the criteria of an ASHRAE level 2 audit. The following five steps listed in the ASHRAE procedures for a level 2 building energy audit were carried out.

1. Walk-through survey of the facility.
2. Data and information collection through meetings with the operator and occupants of the building.
3. Space function analysis.
4. Calculations/assessment of energy use for significant energy end-use categories.
5. Identification of potential EEMs.

The data used in the energy audit process were obtained from the installed building management system that includes temperature sensors, pressure sensors, flow meters, energy meters, power meters, Indoor Air Quality (IAQ) sensors, relative humidity sensors, and advanced controllers to record these data.

Total Power Consumption

The building's total incoming power was recorded for three working days continuously to understand energy consumption patterns (Figure 4). It is observed that the energy consumption pattern during the working days is almost the same. The average minimum power consumption for the three working days is 473 kW and the maximum average is 953 kW.

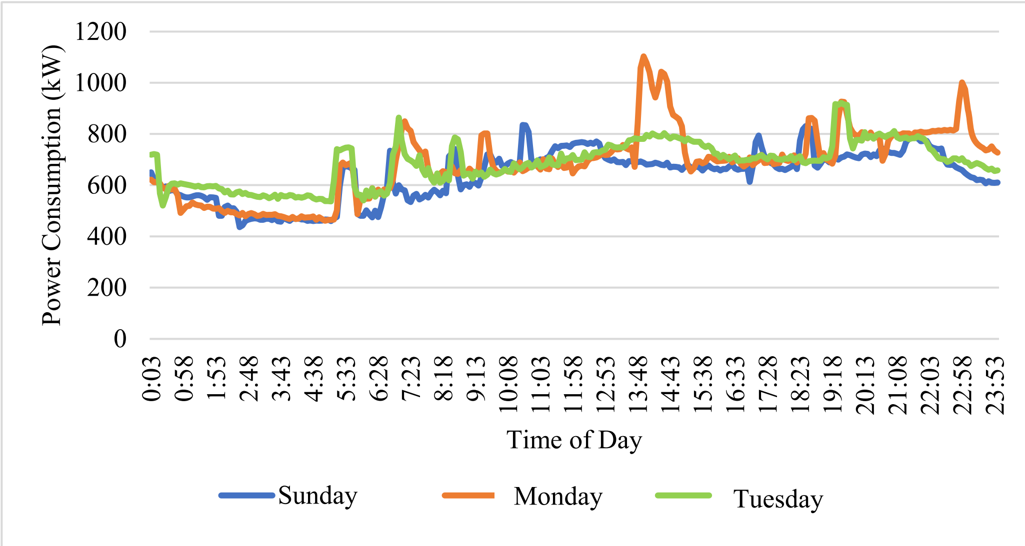

Figure 4. Hourly consumption profile for three typical working days in April 2019.

Chillers' Measurements

To closely observe the building's cooling demand and the chillers' operation, sample data have been analyzed as shown in Figure 5. It presents the cooling load consumption in TR over three days. The daily load profile for the three days is in close proximity. The average minimum load is noted to be 126 TR during the early hours while the load is observed to be, on average, around 350 TR from around noon to afternoon time. The Chillers' power consumption corroborates the cooling demand. The power consumption increases during the time the cooling load demand increases and vice versa.

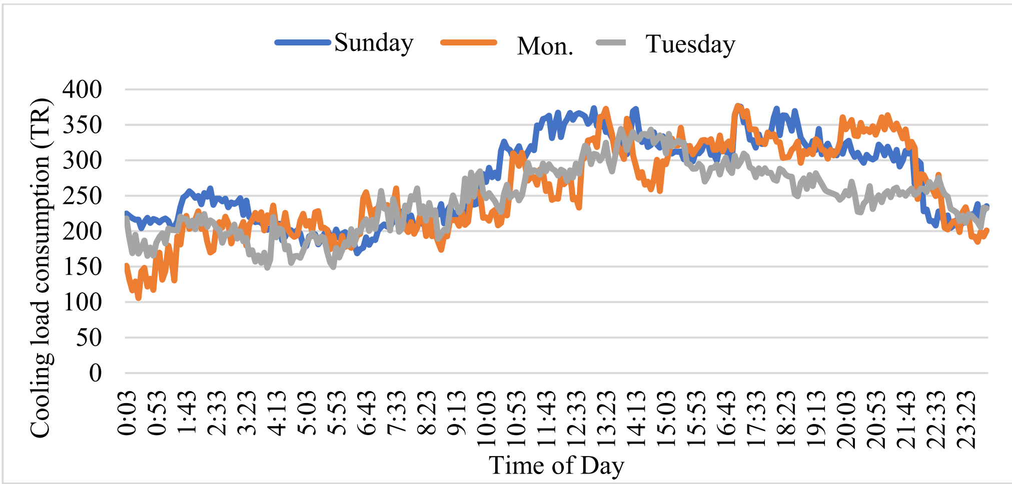

Figure 5. Building cooling load profile for three working days in April 2019.

Indoor Temperature and Load Profiles

The indoor air temperature was measured at different locations in the building to understand the cooling distribution pattern for 24 h (Table 2). Overall, from the temperature ranges, it is observed that the same temperature is maintained throughout the day without considering if it is day and night or if the office is occupied or not. All offices are maintained at the same temperature (22 °C) throughout the day, which indicates the inefficient practice of controlling office rooms' CHIUs.

Table 2. Temperature ranges of various spaces.

Space	Temperature Range
Ground Floor Office (GF)-101	Average temperature: 24.6 °C Maximum temperature: 25.9 °C Minimum temperature: 23.5 °C
GF-102	Average temperature: 21.5 °C Maximum temperature: 25.1 °C Minimum temperature: 18 °C
First Floor (FF)-207	Average temperature: 22.9 °C Maximum temperature: 24.1 °C Minimum temperature: 22.1 °C
Second Floor (SF)-103	Average temperature: 22.3 °C Maximum temperature: 22.7 °C Minimum temperature: 21.8 °C
SF-105	Average temperature: 24.8 °C Maximum temperature: 26.7 °C Minimum temperature: 23.1 °C
Staircase	Average temperature: 30.9 °C Maximum temperature: 33.5 °C Minimum temperature: 28.2 °C
GF-121	Average temperature: 22.4 °C Maximum temperature: 23.1 °C Minimum temperature: 21.6 °C
Auditorium	Average temperature: 25.6 °C Maximum temperature: 27.9 °C Minimum temperature: 22.1 °C

4.2.2. Building Water Consumption

The building receives water from the local national utility. The following readings, taken for the period from January 2018 to December 2018, summarize the water consumption of the building.

- Annual water consumption: 18,720 Cubic Meter (m^3).
- Annual Water cost: USD 26,122.17.
- Water cost/unit: USD 1.25/ m^3.
- Maximum cost: USD 2255.4 in August.
- Minimum cost: USD 1742 in January.
- Water consumption index: 26.7 m^3/m^2/year.

4.2.3. Key Observations

The key observation in the audit process are summarized as below.

Chillers:

- Constant flow chilled water circuit and 3-way valves are installed on the building side.
- Chillers operate at a low temperature difference of 3–4 °C.
- Chillers and pumps operate for 24 h.
- Chilled water set point temperature is maintained at 7 °C throughout the year.

CHIUs:

- Existing CHIUs are provided with permanent split capacitor (PSC) motors. These motors are not controllable and they are always working at a constant speed (full load) and consume full power even if there is no demand.

OAUs:

- All OAUs are operating at full speed continuously for 24 h.
- There is no speed regulation system installed with the OAUs based on the climate or CO_2 level in the indoor air.
- OAU filters were choked with dust.

Lighting system:

- Most of the lights installed in the facility are FTL, CFL, and Halogen types. In common areas such as corridors, reception area, and praying hall, the lights are operating for almost 24 h.

4.3. Implemented Energy Efficiency Measures (EEMs) and Water Saving Measure

Based upon the findings of the energy audit, five EEMs were proposed, and implemented. In addition, water saving was also implemented. The details of the implemented measures are provided in Table 3.

Table 3. Details of implemented EEMs.

No.	Measures	Description of Each Measure
1	Installing chiller plant manager with a smart control system.	An advance controller system used to control the operation of chillers was implemented. It offers energy saving features including dynamic resetting of chilled water supply temperature, proper scheduling/sequencing of the chiller based on dynamic cooling demand, return temperature and ambient temperature, demand limiting based on ambient/building load and history, matching number of pump operations with chiller operation, and monitoring and tracking of the plant performance through energy meter and power meter. The following is the scope of the smart control system: Replacing the existing chiller valve with a motorized valve. Field device installation, cabling. Trace chiller interface card. Design and program of the control system.
2	Installation of adiabatic cooling system for chillers (a retrofit solution that works based on the principle of adiabatic cooling system).	Air-cooled chiller performance depends on the ambient temperature. The higher the ambient temperatures, the lower the chiller efficiency. Adiabatic cooling system splashes water on the air that is used to cool the condenser. When water is exposed to air, it absorbs thermal energy from it, resulting in evaporation. As the air moves through the wet wall, the temperature drops, which in turn reduces discharge pressure in the refrigeration system (chiller) thereby, improving the chiller efficiency. It also helps to keep the condenser coil clean, which enhances the chiller efficiency further.
3	Installing ECM motors with Smart Thermostat for scheduling.	To make the CHIUs more efficient, the Electronically Commutated Motors (ECM) were used. These save energy and improve the efficient movement of air through the CHIU unit.
4	Scheduling of OAU through control system and Installation of Variable Frequency Drives (VFDs).	The OAU filters were cleaned and scheduled to be cleaned frequently. Furthermore, the amount of fresh air was regulated in order to reduce it and accordingly reduce the cooling capacity and power consumption. The VFDs were installed on the OAU to reduce the airflow to the required amount and reduce the power consumption through the fan and chiller.
5	Installation of Light Emitting Diode (LED) lights with Motion Sensors.	All identified existing FTLs, CFLs, and halogen lights were replaced with LED lights to reduce the lighting energy consumption.
6	Installation of water saving devices.	Installed new faucets with aerators for toilet and kitchen basins to reduce the water consumption.

4.4. Cost Analysis

The economic viability of the implemented EEMs was determined by calculating the Compounded Payback Period (CPP) (Equation (1)). The final cost data for each of the proposed EEMs was obtained after the energy retrofit was carried out. The interest rate is considered as 2%.

$$CPP = A + B/C \tag{1}$$

where:

CPP: is the Compound Payback of investments in (Years).
A: is the last period with a negative cash flow.
B: is the value of discounted cumulative cash flow at end of period A (USD).
C: is the discounted cash flow during the period after A.

5. Results and Discussion

This section discusses the energy and water conservation accomplished through the implemented solutions. At first, the savings by each measure are discussed in Section 5.1 and then the whole-building energy consumption for the retrofitted building is presented in Section 5.2.

5.1. Savings Achieved by the EEMs

The installation of smart controls resulted in the reduction in energy consumption of the system by 137,642 kWh (Table 4). This is because dynamic resetting of chilled water temperature saves about 2–3% energy consumed for every 1 °C increase. In addition, demand limiting, chiller scheduling, and avoiding low temperature differences saves up to 15% of the chiller energy consumption. The cost savings by implementing this EEM amounts to USD 6605.8, with a payback period of around 7 years as shown in Table 4.

Table 4. Cost benefit analysis for chiller plant manager.

Description	Value	Unit
	Existing consumption	
Chiller energy consumption	1,971,449	kWh
Total energy cost	94,612.5	USD
	Savings calculation	
% savings on Plant Manager	7	%
Electricity consumption savings	137,642	kWh
Cost savings	6605.8	USD
Investment	41,325.9	USD
CPP	6.8	Years

Moreover, ECM 2 "Installing an adiabatic cooling system" reduced cooling load by 7%. To quantify the savings by the EEM, the efficiency is determined by the dry-bulb temperature and relative humidity levels. Thus, calculating the savings considers the following:

- Direct Savings
  - a. Electricity savings (kWh) = present energy consumption—energy consumption with wet wall system).
  - b. Cooling capacity improvement savings (kW) = present cooling capacity—wet wall cooling capacity).
- Indirect Savings
  - a. Cost savings due to the chiller being under cover during non-operation times, dust-free condenser coil, and temperature data correction.

Figure 6 presents the measured building cooling load profile for the same three typical workdays after the energy retrofitting was done. Compared to the original consumption (Figure 5), the cooling load is considerably less for the building. The installed adiabatic system offered a payback period of nearly five years.

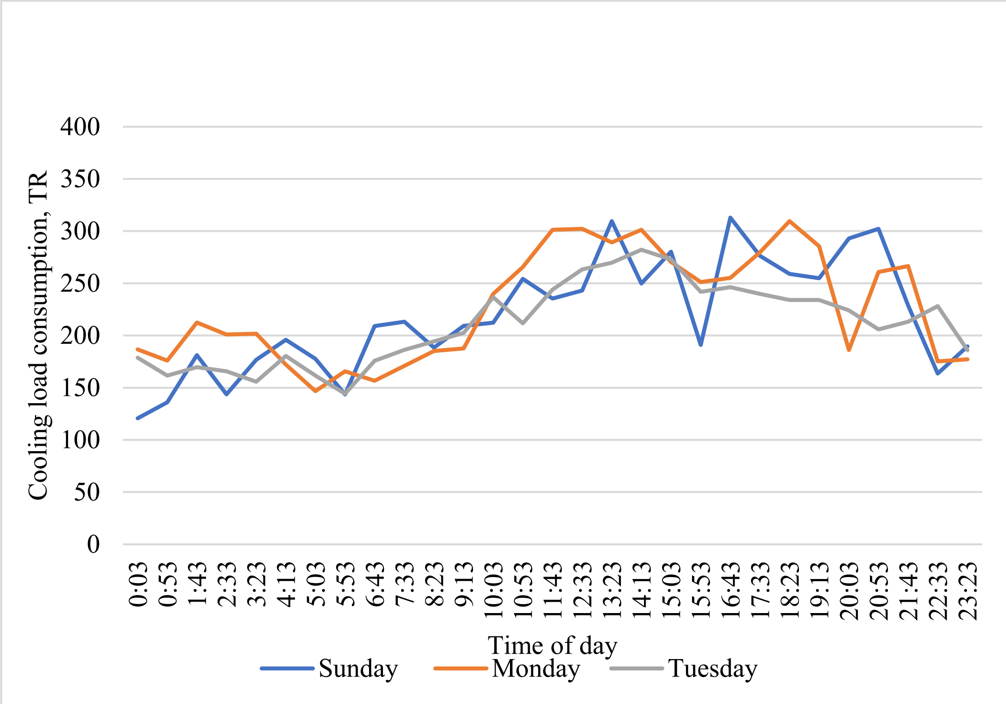

Figure 6. Building cooling load profile for 3 working days (post-retrofit) in April 2020.

Moving forward, ECM 3, 4, and 5 also resulted in energy savings. The used ECM motors, which can adjust their speed according to load requirement, reduced the energy consumption of the CHIUs by a significant amount of 31.8%. It resulted in annual cost savings of USD 4000 that pays back in 6.6 years. Similarly, scheduling of OAU through control system and installation of VFDs reduced the cooling load by 40 TR. The investment had a payback period of 3.9 years. Table 5 presents the energy and economic savings after all the lights were replaced with LED. The lighting load was reduced by almost 64% and the investment had a payback period of 1.9 years. In addition, the water saving measures, as detailed in Table 6, helped reduce annual water consumption by 2200 m^3 saving around USD 2756.6 per year.

Table 5. Cost benefit analysis for LED lights.

Description	Value	Unit
	Existing consumption	
Present energy consumption	432,000	kWh
Total cost	20,732.25	USD
	Savings calculation	
% of Savings on Lighting Load	63.72	%
Electricity consumption savings	275,283	kWh
Electricity cost savings	13,211.2	USD
	Expenses	
Investment	23,995.7	USD
Pay-back period	1.9	Years

Table 6. Annual savings by water saving devices.

Application	Present Flow	Post-Retrofit Flow	Annual Water Savings		Investment	Payback Period
	Liters Per Minute (LPM)	LPM	m^3	USD	USD	Years
Wash basin	7	4	2200	2756.6	7198.1	2.6

5.2. Whole-Building Energy Consumption

A comparison of the post-retrofit data with the pre-retrofit data reveals significant energy savings for the building. The post-retrofit incomer load data as highlighted in Figure 7 shows a reduction in the hourly consumption as compared to the pre-retrofit case (Figure 4). Figure 8, comparing the whole-building energy data from 2018 (pre-retrofit) and 2020 (post-retrofit) with similar weather in the two years, shows a significant saving especially in the peak-load summer months. With 27% improvement, the post-retrofit annual energy consumption turns out to be 2,711,093 kWh. The revised EUI is calculated to be 361.4 kWh/m^2/year. The CPP of the total retrofit investment is found to be six years, which is an acceptable period. The M&V, therefore, suggests that the implemented retrofit measures are effective and financially viable.

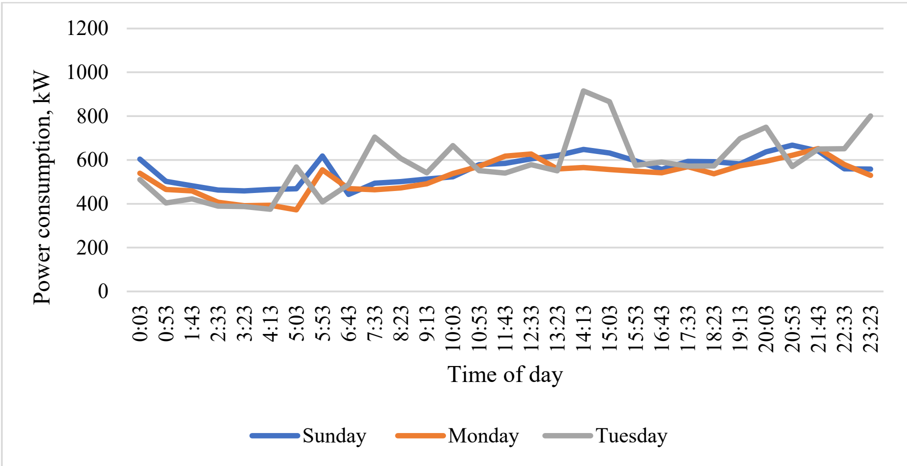

Figure 7. Main incomer hourly consumption profile for Sunday, Monday, and Tuesday (post-retrofit) in April 2020.

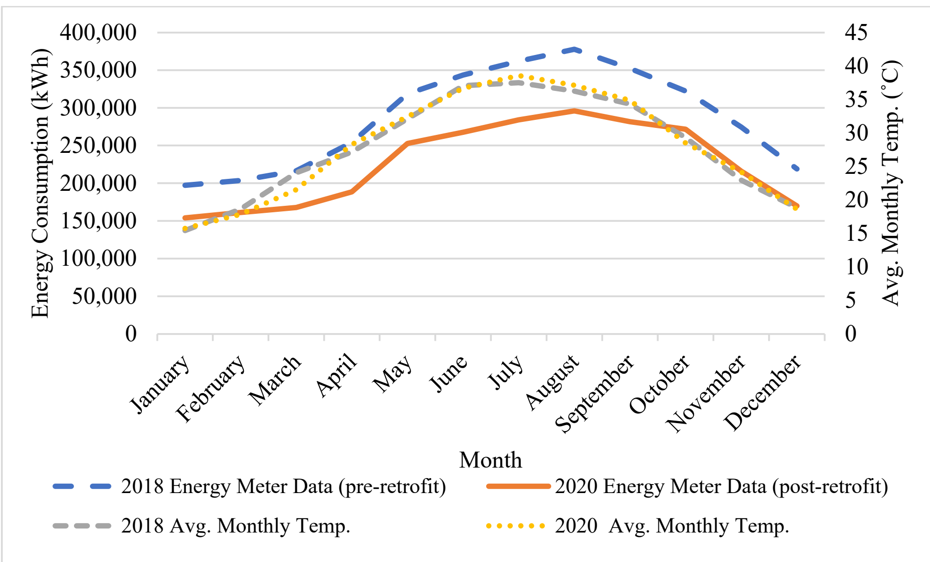

Figure 8. Whole-building energy data (pre- and post-retrofit).

6. Conclusions and Future Work

In this study, an M&V analysis of a post retrofit office building was presented. It was ascertained that pre- and post-retrofit M&V are critical to catalyze and validate energy retrofitting in any particular region. A review of global studies highlighted that IPMVP option C is one of the most widely used M&V methods for comparing whole building energy data. A brief literature review of energy retrofitting studies in the country revealed that there is a critical lack of studies presenting M&V of energy retrofitting projects and most of the studies are mainly simulation-based. In addition, there was a lack of studies focusing on the energy and water efficiency of office buildings. This study successfully covered these gaps by presenting a measured and verified case study of a post-retrofit office building in Saudi Arabia.

The existing office building was highly inefficient with an EUI of 458.9 kWh/m^2/year. The energy audit revealed several areas that could be improved using EEMs. Five EEMs including installing a chiller plant manager with a smart control system, installing an adiabatic cooling system for chillers, installing ECM motors for CHIUs with a smart thermostat for scheduling, scheduling OAU through a control system, installing VFDs, and installing LED lights with motion sensors were implemented on the building. In addition, water saving devices were also installed in the wash basins. The overall energy consumption of the building reduced by 27% in 2020, after the energy retrofitting. This was a significant drop compared to the original energy consumption of the building in 2018. In addition, the water consumption of the building is also reduced by around 12%. Thus, the data proved that implementation of the five EEMS and a water saving measure are effective strategies to retrofit office buildings in the country.

To enhance the research in this area, future studies are recommended to:

- Investigate the use case of advanced M&V or "M&V 2.0" for the M&V of retrofitted buildings in the region. According to the Efficiency Valuation Organization's (EVO) white paper [58], M&V 2.0 can be characterized by "using energy meter data in finer time scales with near real-time access, and Processing large volumes of data via advanced analytics". M&V 2.0 will certainly lead to better results as already shown in a study that used a machine learning-supported methodology to conduct M&V 2.0 [59].
- Consider other M&V options for conducting the post-retrofit M&V including the other IPMVP options as well as the ASHRAE method. Each option is targeting different aspects of buildings; hence, to cover energy retrofitting M&V comprehensively, future studies need to apply the other options for the calculations.
- Identify and establish a decision-making process for energy retrofitting commercial office buildings. Currently, the rate of energy retrofitting of office buildings is almost negligible despite the advantages of energy retrofitting as presented in the case study in this study. One reason for the lagging behind in this area is that the effects of various factors on energy retrofitting such as building ownership type, tenants demands and perception of energy retrofitting, and real estate market location for office buildings is not known for the country. Such a study with policy implications is needed as presented in [60] for the United States.
- Expand on the case study building types, number of analyzed case studies, and the climatic location of the case studies in the country. Post-retrofitting M&V of residential, commercial, public, and governmental buildings in the country should also be presented. In addition, several case studies of all building types, including office buildings, are also necessary to validate energy retrofitting. Furthermore, the different climatic locations in the country should be covered in studies.

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