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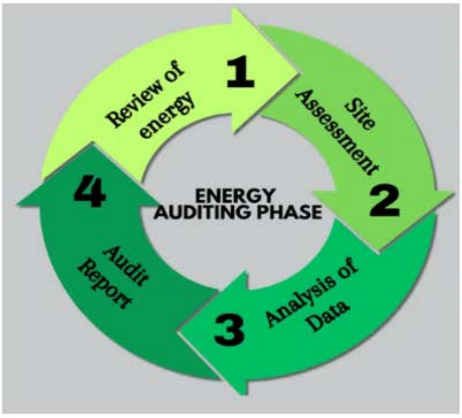
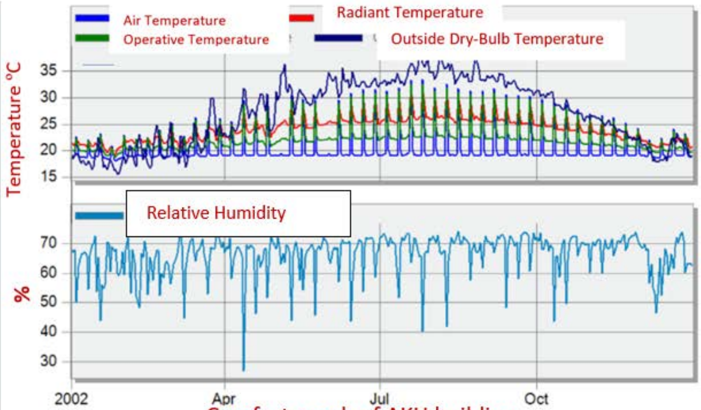
Energy Auditing of HVAC Systems for the Enhancement of Efficiency and Sustainability

Fidhin J. Kandothillath, Fiseha M. Guangul*

Department of Mechanical Engineering, Middle East College, Muscat, Oman





Comfort graph of AKH building

ABSTRACT: Energy audits are crucial for identifying opportunities to enhance efficiency and promote sustainability in the energy sector. In Oman, air conditioning systems account for about 50% of the nation's electricity use, reaching up to 70% in summer due to temperatures as high as 50°C. This study aimed to analyze energy consumption, focusing on air conditioning and refrigeration systems, using an academic building as a case study to improve energy efficiency and sustainability. A series of energy audits identified opportunities for energy conservation in the building's systems. The audit revealed that implementing various low-cost, high-cost, and zero-cost strategies could enhance energy efficiency and sustainability, resulting in an annual energy savings of 37.6%. Zero-cost initiatives, such as turning off HVAC systems when unoccupied, closing main doors, and setting thermostat temperatures to 24°C, reduced energy consumption by 10%. Low-cost measures, including installing occupancy sensors for lighting and ensuring proper HVAC maintenance, led to a 20.8% reduction. High-cost measures, such as installing windows with lower Solar Heat Gain Coefficient (SHGC) values, resulted in approximately 6.8% energy savings.

Keywords: Efficiency; Energy Audit; HVAC; Middle East College; Sustainability.

تدقيق الطاقة لأنظمة التدفئة والتهوية وتكييف الهواء (HVAC) لتحسين الكفاءة والاستدامة

فيدين كاندوثلاث و فيسيها جوانجول

الملخص: تدقيق الطاقة ضروري لتحديد فرص تحسين الكفاءة وتعزيز الاستدامة في قطاع الطاقة. تشكل أنظمة التكييف في عمان حوالي 50% من استخدام الكهرباء في البلاد، وتصل إلى 70% في الصيف نتيجة لدرجات الحرارة التي تصل إلى 50 درجة مئوية. هدفت هذه الدراسة إلى تحليل استهلاك الطاقة، مع التركيز على أنظمة التكييف والتبريد، باستخدام مبنى أكاديمي كدراسة حالة لتحسين كفاءة الطاقة والاستدامة. حددت سلسلة من تدقيقات الطاقة الفرص المتاحة للحفاظ على الطاقة في أنظمة المبنى. وكشف التدقيق أن تنفيذ استراتيجيات مختلفة بتكلفة منخفضة وعالية وبدون تكلفة يمكن أن يعزز كفاءة الطاقة واستدامتها، مما يؤدي إلى توفير سنوي للطاقة بنسبة 37.6%. أسفرت المبادرات التي لا تتطلب تكلفة، مثل إطفاء أنظمة التدفئة والتهوية وتكييف الهواء (HVAC) عند غياب المستخدمين، وإغلاق الأبواب الرئيسية، وضبط درجات حرارة الثرموستات إلى 24 درجة مئوية، عن خفض استهلاك الطاقة بنسبة 10%. أدت الإجراءات منخفضة التكلفة، بما في ذلك تركيب حساسات للإضاءة وضمان الصيانة المناسبة لأنظمة التدفئة والتهوية وتكييف الهواء، إلى تخفيض بنسبة 20.8%. أدت التدابير ذات التكلفة العالية، مثل تركيب نوافذ ذات معامل اكتساب حراري شمسي منخفض (SHGC)، إلى توفير في الطاقة بحوالي 6.8%.

الكلمات المفتاحية: الكفاءة؛ تدقيق الطاقة؛ أنظمة التدفئة والتهوية وتكييف الهواء (HVAC)؛ كلية الشرق الأوسط؛ الاستدامة.

Corresponding author's e-mail: fiseham2002@yahoo.com

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1. INTRODUCTION

The primary driving force behind the 2040 Oman National Strategic Development Plan is sustainable development (Talal Al Rahbi, 2017). In these programs, the human and financial aspects of sustainability may take the spotlight, but the environment also holds a crucial role in the Omani government's commitment to achieving sustainable development. Energy auditing, according to ASHRAE's 2017 definition, is a methodical process that encompasses the recognition, quantification, and examination of energy usage and efficiency within a structure or facility (ASHRAE, 2017). The main goal of energy auditing is to reveal possibilities for improving energy efficiency and lowering energy costs, thereby making a significant contribution to the overall sustainability of a building or facility (Bosu, Mahmoud, & Hassan, 2023).

The Gulf Cooperation Council (GCC) nations exhibit elevated energy consumption due to their warm climate and significant dependence on energy-intensive industries. Considering Oman's hot and humid climate, the energy consumption for air conditioning facilities is substantial. During the summer months, air conditioning systems account for almost three-quarters of the total energy usage. As Oman's population and infrastructure continue to expand, the country's energy consumption experiences a significant increase, necessitating immediate action (Alkalbani & Guangul, 2021; Rumman & Guangul, 2019; TRC, 2016). In a 2017 study conducted by Al-Raisi et al., it was found that air conditioning systems in Oman account for roughly 50% of the total electricity consumption in the country. Peak energy demand in Oman is predicted to increase by up to 11% annually. Since Oman's primary power generation systems are dependent on fossil fuels, the increase in energy consumption would result in a spike in greenhouse gas emissions (Rumman, Guangul, Abdu, Usman, & Alkharusi, 2019). In order to decrease energy consumption, the American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE) has produced a standard that details the energy audit processes. The concept behind an energy audit is grounded in the principles of energy conservation (ASHRAE, 2017). Energy audits provide economic benefits through savings and environmental advantages by reducing greenhouse gas emissions and addressing other impacts of non-renewable energy use. ASHRAE has established a sequence of energy audit levels, denoted as Levels 1, 2, and 3, each delivering progressively detailed examinations and analyses.

In Oman, some researches were conducted on energy auditing to improve the efficiency of energy consumption. Al Rashdi et al., 2022 conducted an energy audit study at International Maritime College Oman (IMCO) to investigate the potential for energy efficiency improvement which will have a positive impact on reducing building operational costs (Al Rashdi et al., 2022). In the study, the annual energy consumption of IMCO buildings was simulated using DesignBuilder software. The simulation findings were validated using monthly actual electricity consumption of billing, and an average deviation of 7.4% was found. To manage and improve energy usage, two solutions were proposed: 1. Replacing old fluorescent lamps with light-emitting diode (LED) lamps. 2. Installing window solar films that can reduce solar radiation. The modelling findings showed that the two proposed solutions could reduce energy consumption by 16% and 7.6%, respectively. A cost-benefit analysis of the findings revealed a payback period of less than 2.5 years for the implementation of the two proposals (Al Rashdi et al., 2022).

The research conducted by Sait, (2013) has examined the electric energy usage of a facility used for education in Rabigh, Saudi Arabia. In the study, the building was thoroughly audited, covering the construction materials utilized, energy use, cooling load, and lighting. Temperature and relative humidity were measured in different locations across the structure. To determine the heat gain and loss from or into the building, thermal images of the interior zones have been taken. Based on the auditing result analysis, certain recommendations were made for reducing electric energy usage, which can reduce up to 35.3%. The efficiency of A/C units can also be boosted by 31% (Sait, 2013).

In an effort to reduce energy consumption in Oman, Al-Saadi (2017) investigated the energy use of a library building at Sultan Qaboos University. The building consists of three floors, has a 2756 m2 total floor space, and uses 1397 MWh on average per year. This building's average energy-use intensity (EUI) is 507 kWh/m2/year. The energy audits have identified numerous energy-retrofitting measures, including replacing the current fluorescent lights with LEDs, turning the air conditioning systems off when the rooms are empty, raising the thermostat setpoint, and reducing air penetration. The building energy model was developed using DesignBuilder and then calibrated based on the field measurements and observations. Several energy management opportunities (EMOs) were assessed using the calibrated model. Only the top four EMOs were chosen. The EMOs include changing the air conditioner operation schedules, replacing fluorescent lighting with LEDs, increasing airtightness, and altering the thermostat setpoint. The findings indicate that 38.5% of the energy consumption would be reduced.

Al-Badi and Al-Saadi (2020) investigated the energy-efficient building methods that can be applied in Oman. For the study, a residential building was taken as a case study which was evaluated using DesginBuilder software. Several energy efficiency measures (EEMs) were investigated, including thermal insulation in the walls and roof, high-performance windows, external shading, LED lighting, and energy-efficient air conditioning. By implementing the proposed EEMs, energy usage has been lowered by up to 37%. Additionally, it was suggested that installing a 6 kW photovoltaic (PV) system and a solar water heater could cut annual consumption by over 50% (Al-Badi & Al-Saadi, 2020).
This research aimed to analyze energy consumption in Oman, particularly focusing on air conditioning and refrigeration systems. The study was conducted at Middle East College, gathering and analyzing relevant data. Recommendations were then developed to improve energy efficiency and sustainability through proper energy conservation methods (ECMs) based on the results of two levels of energy audits conducted to identify areas for enhancement.
Energy conservation methods in buildings entail diminishing energy usage within buildings without compromising thermal comfort. Typically, this leads to enhanced indoor air quality and heightened occupant productivity. While energy conservation initiatives may not immediately yield financial benefits, they bolster national energy security, mitigate environmental pollution, and diminish reliance on fossil fuels, among other advantages (Oyedepo, Anifowose, Obembe, & Khanmohamadi, 2021).

2. METHODOLOGY

In this study, a brief literature review of energy consumption in Oman in general and HVAC in particular was conducted. Furthermore, a related literature on energy audits of the GCC region was conducted. For the case study an administration and library building, Al Khalil Building (AKH building) which is located at Middle East College, Oman was selected. In the energy audit process, the first step was to select a building that serves a longer time for a significant number of people. For the audit, specific parameters of the energy audit, such as the areas that would be examined and the level of the audit were decided. All the necessary data for the selected building was collected. Architectural design blueprints, electrical supply, metering, and energy usage details were collected. Certain qualitative methods, such as questionnaires and surveys distributed to building users and maintenance technicians. A field investigation was conducted to find out how much energy was used by various parts and spaces. The analysis of energy use was built on the basis of the site assessment and the collection of primary data.
For the energy audit, the following procedures were followed.

- Lighting Audit: A lighting audit involves a thorough inventory of all lighting fixtures in a building and an assessment of their usage.
- HVAC System Audit: An HVAC system audit encompasses an evaluation of the heating, ventilation, and air conditioning systems in a building. It includes an examination of air distribution and control efficiency.
- Occupancy Behavior Analysis: The study evaluated the potential for energy savings by analyzing occupancy schedules and occupant behaviour to assess the regulation of lighting, plug loads, and other operational measures.
- To simulate energy consumption and performance under various circumstances, computer-based energy modelling software was employed. This technique assists in evaluating the outcomes of suggested energy efficiency solutions before they are put into action. The energy modelling process was carried out using DesignBuilder software. The simulation was carried out using EnergyPlus software. The software delivers a full evaluation of a building's efficiency, considering all facets of energy use, thermal comfort, daylighting, natural ventilation, and HVAC systems. The software allows users to import building data from other programs such as AutoCAD. DesignBuilder has modules for checking whether energy codes such as Leadership in Energy and Environmental Design (LEED), Building Research Establishment Environmental Assessment Method (BREEAM), and ASHRAE have been followed. Using parametric analysis, users can evaluate numerous design options and systems, identifying the most cost-effective options and improving building efficiency.

Following the preceding procedures, the acquired data was examined to determine the type of measure to be performed, such as zero-cost (ZC), low-cost (LC), or high-cost (HC). Based on the information gathered, the facility was inspected to identify locations where considerable energy savings may be realized. Levels 1 and 2 energy auditing were chosen to satisfy the desired objectives since the two levels are within the scope of the study.

2.1 Location

For the study, the AKH building, a two-story educational facility with a total floor area of 4,062 square meters, located within the Middle East College campus was selected. The college is situated within the Knowledge Oasis Muscat (KOM) technology park. Oman experiences a hot, arid desert climate with minimal annual rainfall, and it features two distinct seasons: summer and winter. Figure 1 depicts the average monthly climatology of the lowest, mean, and maximum temperature from 1991 to 2020. The summer season, which is characterized by hot and dry weather, typically lasts from April through September. The relative humidity is likewise at its lowest during this period. During the winter season, which lasts from October to February, the temperature drops substantially and is typically pleasant, with the lowest temperature falling below 15ºC (The-World-Bank-Group, 2021).

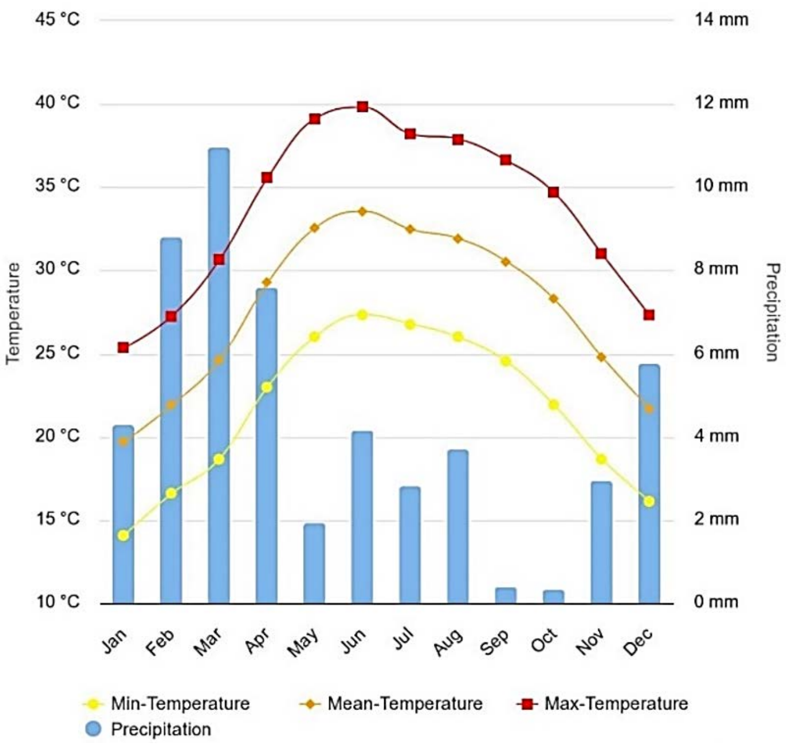

Figure 1. The weather data for Oman (The-World-Bank-Group, 2021).

2.2 Types of energy audit

In the process of conducting an energy audit, it is imperative to employ a rigorous and scientifically oriented approach to ensure the identification of all potential opportunities for improving energy efficiency. ASHRAE has developed a set of energy audit levels, denoted as Level 1, 2, and 3 energy audits (ASHRAE, 2017), which offer progressively increasing levels of data and analysis. ASHRAE recommends commencing with a Level 1 audit and advancing to a more comprehensive Level 2 or Level 3. The choice of the most suitable audit level for a particular facility depends on the specific goals of the audit and the available resources. Some facilities with less demanding requirements may suffice with a less extensive audit. However, other facilities may require additional time and in-depth research to achieve their energy efficiency objectives. An energy audit depth should ensure a suitable balance of audit value and cost (Deru, Deru, & Kelsey, 2011). Level 1 and Level 2 energy audits were carried out in the current study. Level 3 energy audits were not performed since they demand more resources and technology for monitoring and recording the energy use of specific components (Baechler, 2011).

Level 1 Energy Audit

• Review electric utility bills and other energy consumption to identify patterns and amounts of energy usage.

• Review the air conditioning system's design and operation to uncover easy and low-cost energy-saving solutions by optimizing the settings of the thermostat, insulating and sealing the ductwork, and cleaning and maintaining equipment.

• Establish the building's baseline energy performance by comparing the current energy use to industry benchmarks and similar buildings.

• Identification of potential areas for additional inquiry in a more comprehensive audit, such as excessive or underperforming equipment, or systems that are not adequately managed or maintained.

Level 2 Energy Audit

• In-depth review of energy consumption data was conducted to identify specific areas of excessive energy use or potential inefficiencies in the air conditioning system.

• Measure and test the air conditioning systems and equipment on-site to get thorough information on energy use that comprises testing equipment, measuring airflow, measuring static pressure, and temperature differentials.

• Review the mechanical systems and HVAC controls of the facility. This involves updating to more energy-efficient equipment, installing demand-controlled ventilation, and installing energy management systems.

• Explore and assess energy harnessing options for the air conditioning system, such as on-site electricity production using solar and wind energy.

• Draw up a list of proposed energy-saving measures for the air conditioning system, together with cost and savings estimates.

2.3 Data collection

The campus service head office and the maintenance and housekeeping office provided the information needed to conduct the energy audit. One of the techniques utilized to get information on building operations was conducting in-person interviews with personnel in charge of the college's infrastructure, operation, and maintenance. Meetings were held with the campus service manager, maintenance and cleaning staff, and technicians. For the period 2019–2022, information on the building's power consumption was gathered. Due to the campus closing and the switch to online learning as a result of the COVID-19 pandemic, the study did not include data from the years 2019, 2020 and 2021. The college reopened in 2021. As a result, the analysis relied on electricity data from 2022, when the college was fully operating. The consumption figures are for the period January 2022 to December 2022. The campus only uses power from the public grid for the building's energy demands. The AKH building has a total of seven meters dedicated to the air conditioning units. As a result, it was possible to compute the electricity needed for air conditioning directly. The HVAC system accounted for 67% of the energy consumption in this building.

Level 1 Energy Audit

In the beginning, a walk-through audit was performed to carefully evaluate all of the building's operations, practices, and controls. A thorough visual audit of the building's electrical equipment was performed to gauge its energy consumption and identify opportunities for energy-saving measures. Numerous noncompliance issues were discovered in the building during the inspection. The walk-through evaluation identified a number of issues, particularly those specified in ASHRAE Standard 100-2018, which are addressed in the following sections.

Electricity usage

The electricity consumption details were collected for one year when the college was fully operational. In the instance of the AKH building, checking the electricity bills revealed that HVAC consumes up to 67% of total energy as shown in Figure 2. In the figure, the red line depicts the electricity consumed by appliances with air conditioning, while the blue line depicts the non-AC appliances. The total amount of energy consumed by the building in 2022 was 498 MWh For the same year, the tariff cost was 26 baiza/KWh. About 335 MWh, or 67% of the building's electrical use, was consumed by the HVAC system. Because of the winter weather, energy use drops in January. The drop in February and July was due to the closure of the College for semester vacations. Peak consumption occurs throughout the summer months. Later in the year, as the country gets closer to winter, less electricity is used.

Building characteristics

The library, human resources department office, the electric room, and the storage are all located on the right side of the building's ground floor, which has a total area of 2067 m2. On the left, a general computer lab is located. The first floor, covering an area of 1995 m2, comprises a pantry, a private study room, and offices. The majority of the roof was constructed from a low-insulating material, which increased the structure's heat gain and led to a higher energy consumption. The building's roof is built of a 200 mm-thick concrete slab. The walls were constructed with concrete blocks. The concrete blocks were plastered with 30 mm cement on both sides. The walls and windows are described in detail in Table 1.

The building is facing north, which helps to block direct sunlight and results in cooler indoor temperatures than a building facing south. The main entry is a sliding door that opens automatically and is located on the north side. There are no modes for natural ventilation in the building, and the windows are non-opening types. Figure 3 depicts a 2D-floor layout of the ground floor, complete with cassette-type air conditioners. The building has windows in the middle of the roof that are coated with UV-protected polycarbonate sheets to allow for daytime light.

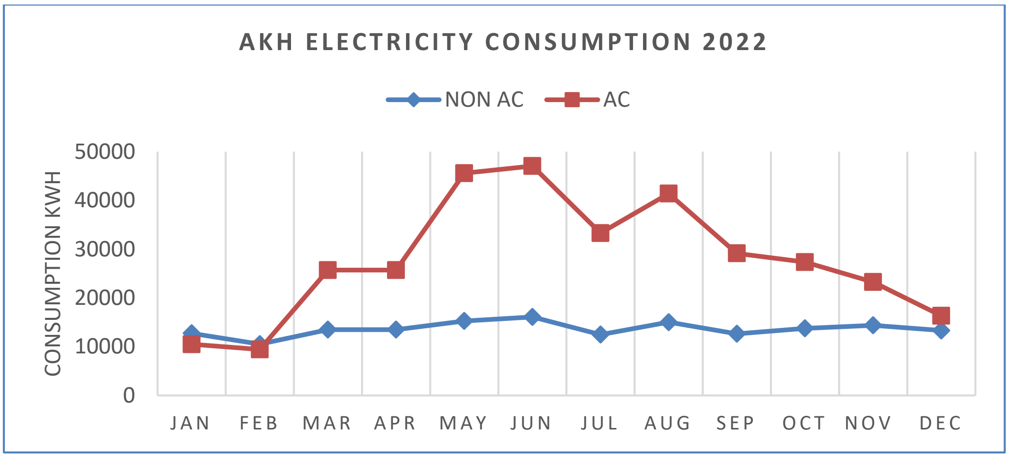

Figure 2. AKH building electricity consumption in 2022.

Table 1. Material used for walls and windows

Building part	Materials Used	Heat Transfer Properties
Wall	0.03 m cement plastering on both sides + 0.2 m medium-weight concrete block	Heat transfer coefficient (U) = 0.07 W/m2. K Thermal resistance (R) = 9 m2. K/W
Windows	Tinted 6 mm double-glazing windows	Solar heat gain coefficient (SHGC) = 0.43 Heat transfer coefficient (U) = 3.157 W/m2. K

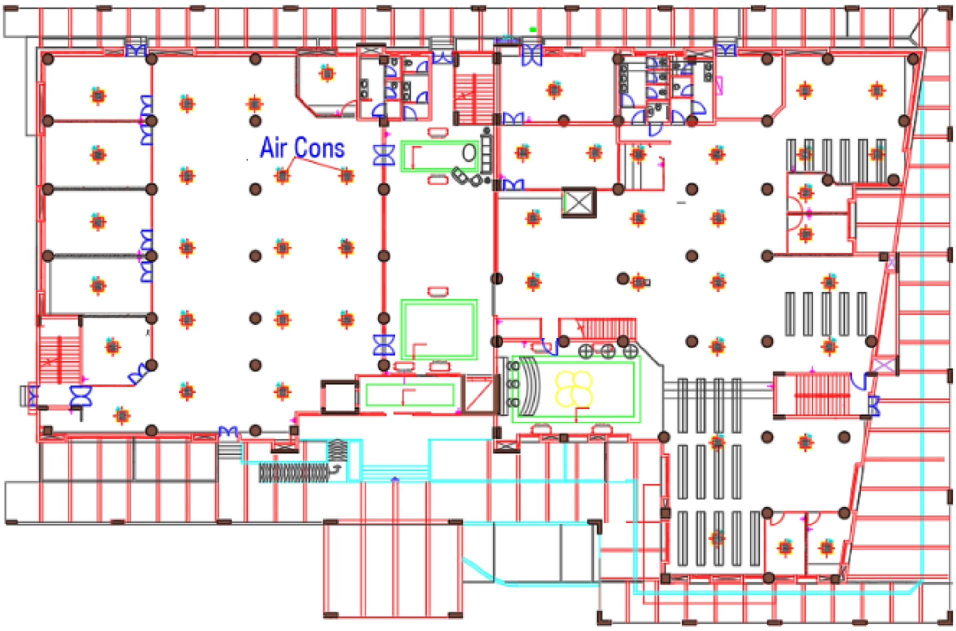

Figure 3. AKH ground floor with AC layout.

HVAC characteristics

In the AKH building the Variable Refrigerant Flow (VRF) system is used to cool the structure utilizing cassette-type ACs. A VRF system is a kind of HVAC system designed to provide efficient cooling for large commercial or residential structures. Both variable refrigerant volume (VRV) and variable refrigerant flow (VRF), which are frequently used interchangeably, are terms for the same technology. Since VRV has been trademarked by Daikin Industries, Ltd., all companies who copy this technology refer to it as a VRF system (Aynur, 2010). In a VRF system within the AKH building, a network of refrigerant pipes connects a sole outdoor unit to multiple indoor units. The outdoor unit houses the compressors, which are responsible for supplying refrigerant to each indoor unit. This specific VRF operates exclusively for cooling purposes since heating is not required. Each outdoor unit possesses a working capacity of 28 kW. The building has 68 cassette-type air conditioners.

Notably, each outdoor unit comprises three compressors within a single unit, categorized as large, medium, and small, drawing 5.8 A, 4.6 A, and 3.5 A, respectively.
R22 refrigerant is used in the existing system. A leak in the system that could affect cooling is indicated when the pressure drops below 60 psi. This is routinely examined by the maintenance crew using the company I general HVAC software. The VRF cooling-only system, as opposed to other HVAC systems, is the best choice for the existing AKH building in Oman because of its zoning capabilities, energy efficiency, temperature control, and scalability for future expansion. The VRF system, however, has certain drawbacks. Any obstruction would hinder the operation of every interior unit connected to the condensing unit, which is shared with numerous evaporator units.

Lighting

A preliminary walk-through revealed the building utilizes LED lighting. The building originally used fluorescent lighting, but in recent years it has changed to LEDs. Throughout the building, 523 lighting systems of six different types are fixed. Regardless of use, the inside lights of the library and computer lab are on from morning to night.

Level 2: Energy audit

A level 2 energy audit examines the amount and efficiency of energy use in a facility in greater detail. In comparison to level 1, it comprises a more extensive analysis of equipment performance, energy use patterns, and potential energy-saving strategies. At this stage, a survey that gauges the satisfaction of users of the facility (students and staff) were conducted. Moreover, a building energy model simulation was conducted to understand the most efficient energy conservation method (ECM) and enable decision-making based on data.

Thermal comfort survey

To better understand the performance of the building, a survey was carried out. Students and staff were chosen at random to participate in the survey. The survey's questions primarily addressed the use of the air conditioner and lighting and indoor thermal comfort. The survey's findings, as displayed in Figure 4, indicate that 51.6% of respondents said the library's temperature is "too cold." Therefore, energy can be saved by regulating the room temperature to a comfortable level.

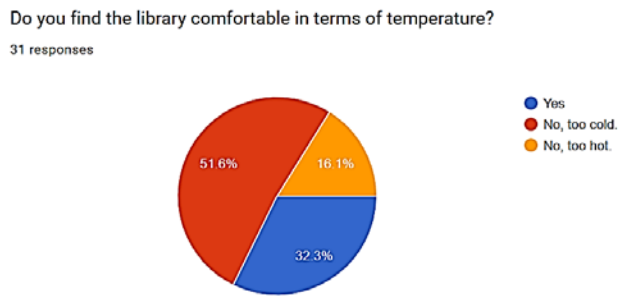

Figure 4. Survey result on library thermal comfort

AC Cooling efficiency

Temperature T or delta-T is one of the most commonly used measurements in HVAC performance evaluation. Monitoring delta-T over time can alert users to poor system performance, unnecessary energy use, or impending equipment failure, allowing one to take preventative action (Lee, Yoon, & Won, 2022). Below is the formula outlining how to calculate cooling effectiveness:

$$\Delta T = return\ air\ temperature - Grill\ temperature$$

The delta-T value must be more than 15°C for the AC unit to provide appropriate cooling. A low delta-T could be experienced due to airflow restrictions, low refrigerant levels, or system failures. On the other hand, if the delta-T is very high, it may indicate filter clogging, insufficient airflow, or overcooling. Hence, by measuring the temperature differential, HVAC technicians can determine whether the system is working properly or not. The Elitech RC 4HC temperature logger was utilized to measure the temperature in the current study.

Lighting controls

There are various technologies that can be utilized to control the lighting system using the occupancy sensors. The most often used sensors in commercial buildings are Passive Infrared (PIR) and ultrasonic occupancy sensors. PIR sensors use a distinction between the heat emitted by moving people and the surrounding heat to detect the presence of people. Ultrasonic sensors emit sound waves and detect frequency changes caused by moving objects or people, indicating their presence (Cheng, Fang, Yuan, & Zhu, 2020).
To calculate energy saved by the occupancy sensor, the following equations are used.

$$\begin{aligned} Energy\ usage\ without\ occupancy\ sensor \\ &= Power\ consumption\ of\ lights \\ &\times Number\ of\ lights \\ &\times Operating\ hours \\ &\times 365\ days\ per\ year \end{aligned}$$

$$\begin{aligned} &Energy\ usage\ with\ occupancy\ sensor \\ &= Energy\ consumption\ (without\ occupancy\ sensor)\ x\ (1 \\ &- Occupancy\ rate) \end{aligned}$$

The electricity saved can also be found as:

$$\begin{aligned} &Electricity\ saved \\ &= Energy\ consumption\ (without\ occupancy\ sensor) \\ &- Energy\ consumption\ (with\ occupancy\ sensor) \end{aligned}$$

Table 2. Difference between PIR and Ultraviolet sensors

	PIR sensor	Ultraviolet sensor
Technology	Passive Infrared (PIR)	Ultrasonic
Detection Principle	Identifies the distinction between background heat and heat given out by the motion of people.	Sends out ultrasonic sound waves, measures how quickly they are returned, and searches for frequency shifts brought on by a moving object.
Coverage	Necessitates a clear line of sight between the sensor and the passengers.	Covers the entire area and finds persons hidden behind objects.
Suitable Spaces	Wall switch replacements, high ceilings, high airflow, direct visibility, and enclosed spaces are some examples of situations that need chosen coverage.	Restrooms, open offices, enclosed halls, and stairways, areas needing a higher level of sensitivity, segmented spaces.
Setbacks	Low amounts of occupant motion, obstructions in the way of the sensor's field of view, and sensors installed on sources of vibration.	High levels of vibration or air flow that cause bothersome switching, and open spaces that call for selective coverage, such as the control of individual warehouse aisles.

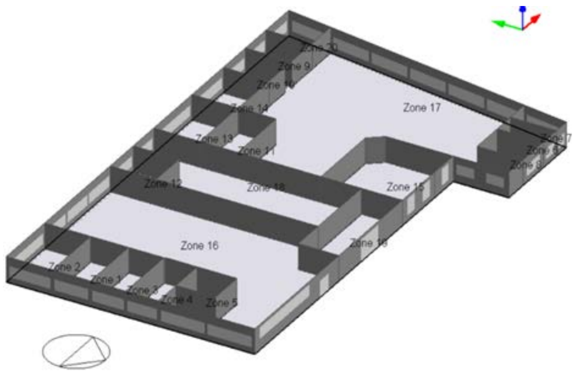

Figure 5. The different zones on the ground floor of the AKH building.

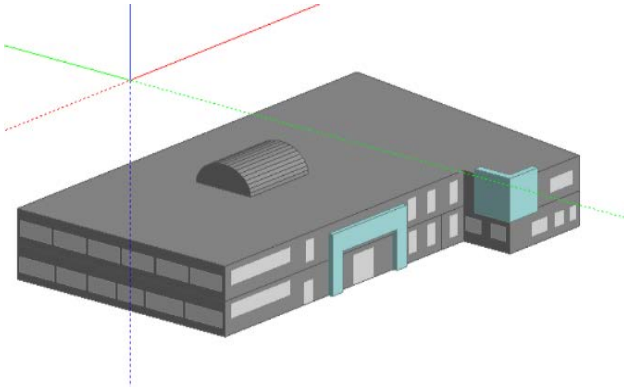

Figure 6. AKH building 3D model.

Simulation of the building

The goal of this section is to provide an overview of the development of a calibrated building energy simulation model for the AKH building. The simulation model of the existing facility was made using the DesignBuilder application and calibrated using data acquired during an energy audit of the structure. The Seeb International Airport in Oman has been chosen as the designated location template for the building in the DesignBuilder. This location's latitude and longitude are 23.6 and 58.3 degrees, respectively. Drawing Exchange Format (DXF) files from AutoCAD were imported into DesignBuilder for the simulation's purposes, where they were used to create the building geometry. According to the plan, a 3D model of the building was made. The site orientation was determined by the direction of the north. Based on the structure's dimensions and level count, a model of the building is created. In addition, a window-to-wall ratio of 40% glass was considered. The building was divided into multiple sections according to the services provided in each zone. Figure 5 and Figure 6 depict the AKH building's exterior and exterior-generated 3D model. The VRF system was chosen for the HVAC system, and the building's cooling temperature was specified as 18°C. The previously discussed building materials were entered into the program.

3. RESULTS AND DISCUSSION

Numerous issues came to light during the energy audit of the AKH building. Upon a thorough examination of the electricity bills, it became evident that a substantial portion of the building's electricity consumption could be attributed to the HVAC system. In the year 2022, the total energy consumption for the building amounted to 498 MWh, with HVAC accounting for 67% of this electric energy consumption.

The most suitable choice for the current AKH building is the cooling-only variable refrigerant flow (VRF) system. This choice is made based on its capacity for zoning, its energy efficiency, temperature control capabilities, and its adaptability for future expansion. Cost can be further reduced through improved operational practices. The VRF system has drawbacks. As one condensing unit is linked to multiple indoor evaporators, obstructions on it can disrupt all connected indoor units, resulting in an unfavourable indoor environment.

3.1 Cooling Efficiency

To check the cooling efficiency, ΔT was calculated. ΔT was calculated by subtracting the grill air temperature from the return air temperature.

$$\Delta T = return\ air\ temperature - Grill\ temperature$$

$$\Delta T = 26 - 13 = 13°C$$

The value of ΔT of 13°C indicates that the HVAC system is not efficiently cooling the area, which is below the manufacturer's (i-general) recommended range of 15°C to 23°C. An inspection is required if the value does not fall within the range. Three out of the ten randomly tested air conditioners failed to meet the acceptable ΔT value, suggesting that maintenance is needed for those units.

VRF systems need to be regularly maintained in order to maximize energy efficiency, improve system lifespan, and enhance indoor air quality. The performance of a system might be affected by ineffective components, clogged coils, or unclean filters that impede airflow. Examining electrical connections and verifying the refrigerant level are required to ensure maximum efficiency. Proper maintenance of the AC would increase energy savings (Au-Yong, Ali, & Ahmad, 2014; de Souza, Rosa, Evangelista, Tam, & Haddad, 2021; Springer & Dakin, 2013).

The HVAC system is intended to keep the building's atmosphere stable by guaranteeing proper temperature, air quality, and humidity levels. When doors are left open, cool air escapes, causing the system to operate longer to compensate. As a result, energy consumption and power bills will increase. Furthermore, external pollutants such as pollen and dust can enter the building, reducing air quality and potentially affecting the comfort of occupants. From the DesignBuilder simulation analysis, it is obtained that locking the doors in the library and computer lab would save 1.3% of the energy consumed by the HVAC system by preventing infiltration of the air.

Running HVAC systems when the rooms are not occupied will incur unnecessary energy costs. This includes not just energy-related costs but also wear and tear on the equipment, which could result in increased regular maintenance and a shorter system lifetime. Multiple temperature settings can be made based on occupancy rates utilizing programmable thermostats. As a result, the system can operate efficiently during peak hours while using less energy during off-peak hours. By turning off the HVAC under no occupancy, 5.2 % or 25920.46 kWh/year of energy could be saved.

During the HVAC energy auditing, a number of issues were found. The internal comfort graph for the building is depicted in Figure 7, was obtained using the DesignBuilder program.

Based on the simulation results, we can observe variations in the outside dry bulb temperature (represented by the dark blue line), which signifies the air temperature without factoring in humidity. In January, this temperature is at its lowest, reaching just 14°C, whereas during the summer months, it soars to 38°C, reflecting the typical weather conditions in Oman.

The Radiant temperature (depicted by the red line), a crucial factor in assessing human thermal comfort as it regulates the exchange of heat between individuals and their surroundings, exhibits an average of 25°C during the summer and 23°C in the winter. When considering thermal comfort, it is essential to take both dry bulb temperature and radiant temperature into account. The combined influence of these parameters, known as the operative temperature, provides a more comprehensive understanding of the thermal conditions experienced by individuals in a specific environment. The operative temperature, represented by the green line, falls within the range of 20°C to 22°C. This metric serves as a measure of the overall thermal comfort experienced by people in that particular setting. The basic principles manual of ASHRAE (2001) states that the ideal temperature for summer comfort is 24 °C. From this perspective, it is clear why 51.6% of the respondents in the present survey indicated that the weather was "too cold" for them. Izzati et al. (2022) investigation also revealed that the mean comfort temperature was 24.3 °C based on the responses of the occupants (Izzati et al., 2022). Stable temperature conditions are essential in an air-conditioned space. Even little comfort variations can be uncomfortable in particular settings, such as offices and educational facilities, and have a detrimental effect on both productivity and health (Cui, Cao, Park, Ouyang, & Zhu, 2013). Consequently, raising the thermostat to 24 °C would increase comfort while saving 3.5% on energy.

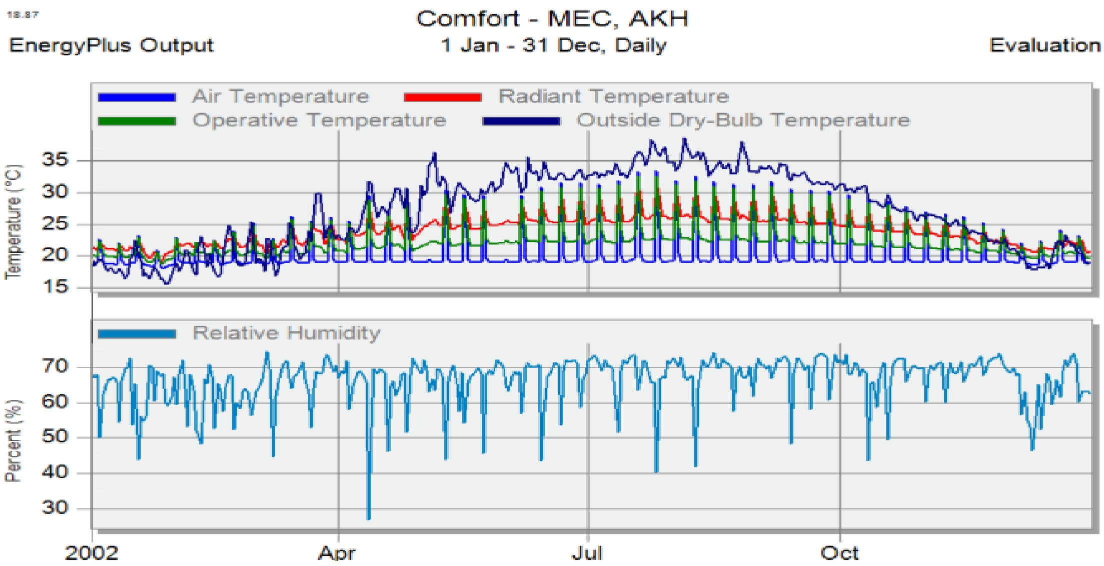

Figure 7. Comfort graph of the AKH building

3.2 Shading Effect

The impact of shadows on the structure for the entire year was determined by constructing the sun path in DesignBuilder, as shown in Figure 8. The structure is situated in a low-lying area with no nearby buildings or trees to give shade. According to this fact, the building is directly exposed to solar radiation from sunrise to sunset. The sun rises in the east and sets in the west. In the afternoon, the entire west side receives direct solar rays.

Planting trees would offer passive cooling for the structure and shield it from the sun's strong rays, especially on the east, west and south sides. Trees and other flora help to offer a cooling impact to the building by absorbing heat from the surroundings through the process of evapotranspiration (Bhamare, Rathod, & Banerjee, 2019). As a result, the building's cooling demand will be decreased. Additionally, trees make the area more aesthetically pleasing and increase the amount of oxygen in the air.

3.3 Changing to the latest technology

The existing HVAC system in place utilizes a VRF system powered by a reciprocating compressor. This system relies on R22 refrigerant, which is now considered outdated compared to R410A. However, advancements in HVAC technology have introduced inverter-driven rotary compressors. Upgrading to inverter-driven rotary compressors and transitioning to R410A refrigerant offers numerous benefits in terms of energy efficiency and performance, and in advancing sustainability objectives (Chen, 2008; Oruç & Devecioğlu, 2020). Transitioning to this latest technology requires a complete retrofitting of the entire HVAC system, which may lead to significant disruptions in the building's operation. Therefore, a thorough investigation is necessary before making any recommendations. This investigation should evaluate factors such as feasibility, cost-effectiveness, and potential impacts on the building's functionality and occupants.

3.4 Environmental Aspect

R22 is a hydrochlorofluorocarbon (HCFC) refrigerant that depletes the atmosphere's ozone layer and contributes to global climate change when released into the atmosphere. According to the US Environmental Protection Policy (EPA), R22 emissions are one of the main reasons for an ozone hole formation above the South Pole (Andersen, Sherman, Carvalho, & Gonzalez, 2018; Miller, Latino, Konidala, & Patenaude, 2021). Because of regulatory limits, many countries have phased out or significantly reduced R22 production and imports. As a result, this may lead to a high cost and difficulty in acquiring R22 refrigerant for maintenance and servicing in the future. In the case of refrigerants used in VRF, ammonia has the highest coefficient of performance (COP), whereas R410A has the next highest COP (Saab, Al Quabeh, & Ali, 2018). When compared to R410a, the use of ammonia improved VRF system performance by 24%. Ammonia, on the other hand, is rarely used in such systems due to its toxicity. Hence, VRF systems that use R410A refrigerant are the best option. The technological developments and the use of more efficient R410A refrigerant against R22 refrigerant boost cooling efficiency by more than 35% (Daikintech; Goetzler, Guernsey, Young, Fujrman, & Abdelaziz, 2016; Hernandez III & Fumo, 2020). A VRF system that uses R410A and ensures compliance with current and future environmental criteria is a more sustainable and long-term choice. As energy efficiency increases, lower energy use means cheaper energy prices and lower CO_2 emissions. To reduce reliance on electric lighting and conserve energy during the daytime, natural daylighting can be used instead of electric lighting. This method entails carefully managing the introduction of natural light, direct sunlight, and diffused skylight into a building (Wong, 2017). Figure 9, generated from the DesignBuilder simulation, illustrates the extent of natural light penetration through the windows.

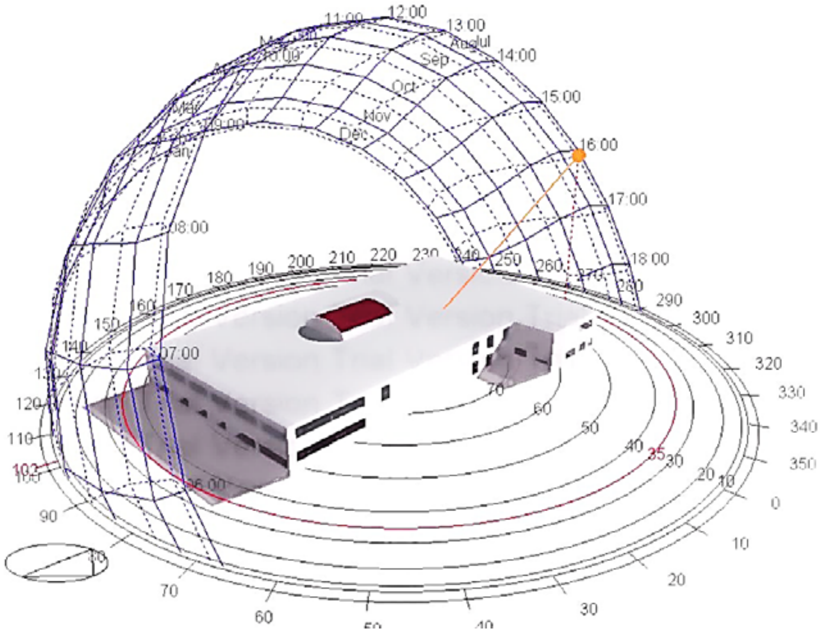

Figure 8. The building's shadows and sun path at 16:00 on June 5.

Light intensity might range between 200 and 1000 lux in areas near windows. Office areas, libraries, and computer labs have light intensities of 300, 500, and 700 lux, respectively. Hence, in certain places, reducing lighting intensity during the day by balancing natural and artificial light could contribute to energy-saving strategies. Using sunlight can reduce reliance on electric lighting, which reduces the heat produced by lighting fixtures. As a result of the reduced heat gain from lighting, the building's cooling requirement could be reduced.

3.5 Effect of Glazing

When windows account for 20-30% of the surface area of a wall, they contribute 45-60% of the building's cooling load (Bhamare et al., 2019). The heat balance graph displayed in Figures 10 and 11 can help to clarify the solar heat gained through the windows. The graph in the figures shows the total heat removed (blue line) from the space and the total heat gained through the windows (yellow line) due to solar radiation for each day starting from 12 AM.

The indoor environment absorbs heat from external sources like solar radiation entering through windows, as well as heat transfer through walls, and from internal sources such as lighting, electrical appliances, and human occupancy. The yellow line in Figure 9 shows the solar heat gain from the solar radiation through the 6 mm tinted double-glazing windows with a Solar Heat Gain Coefficient (SHGC) of 0.430. From the figure it is evident that the solar heat gain is relatively low in the afternoon, reaching 26 KW. Conversely, it exhibits higher values during the early hours of the day and in the evening, peaking at 38 KW. Furthermore, over the course of the week, the average sensible cooling value is 300 KW. In the graphs, the sensible cooling load are depicted as a negative value, whereas heat loads gained by the indoor space are depicted as positive numbers.

The solar gain through the windows reduces to 10 KW in the morning and afternoon, and 5 KW in the evening when the solar tint is changed to double Low Emissivity (LoE) special tint 6mm glass with SHGC = 0.298, as illustrated in Figure 11. By utilizing this glazing, the solar gains through windows have decreased. Due to the reduced amount of heat that needs to be removed from the room, the sensible cooling value also dropped. This lowers the need for cooling and, thus, the amount of cooling energy used.

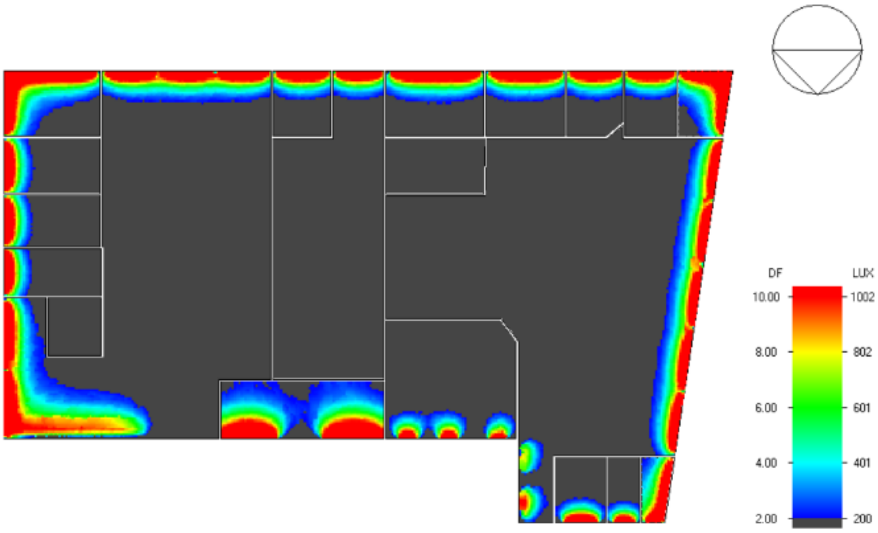

Figure 9. Natural light pictures for the AKH building on the ground floor.

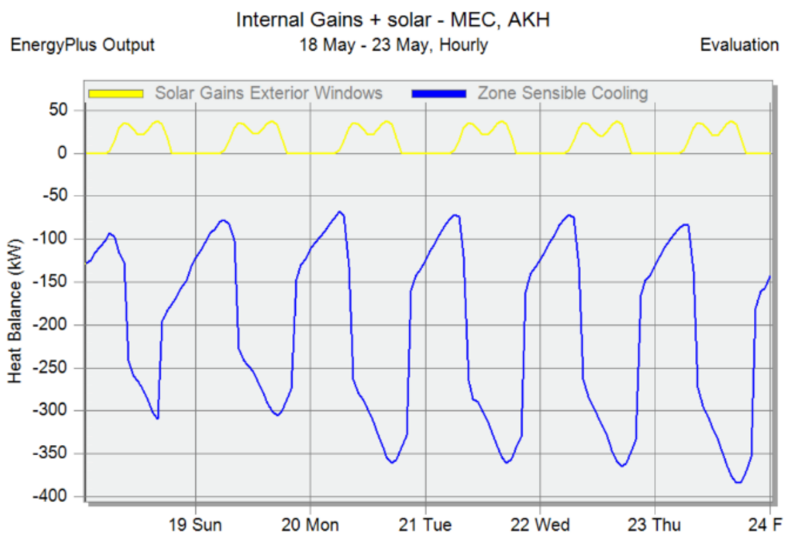

Figure 10. Heat balance for tinted double glazing 6mm glass (SHGC=0.430)

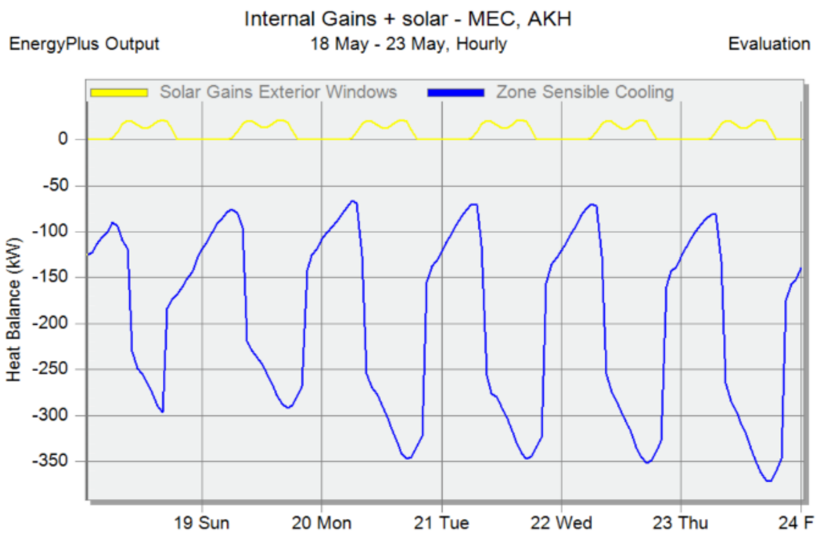

Figure 11. Heat balance for LoE special tinted double glazing 6mm glass (SHGC=0.298)

3.6 Cost savings

The energy cost saving, initial investment cost and the payback period for installation of PIR sensors were determined by considering the required number of PIR sensors and the market current price using the formula indicated in section 2.3. Therefore, through the installation of sensors, it was determined that energy savings amount to 96,154 kWh/year, translating to 2500 OMR. The initial investment for the PIR was approximately 156 OMR, with a projected payback period of no more than one month. The cost saving by using LoE special tint glass is calculated considering the total window area as shown in Table 3.

Table 3. Cost of applying the tinted glass windows

Window area (m^2)	Price of the LoE special tint glass (m2)	Total cost (OMR)
1358	2.5 OMR	3395

Considering 0.026 OMR/kWh energy cost, the amount of savings every year by applying the recommended LoE special tint glass is about 900 OMR. Hence, the payback period on investment can be determined as,

$$Payback\ Period = \frac{Initial\ investment}{annual\ return} = \frac{3395}{900} = 3.77\ years$$

Hence, if the proposed LoE special glass is used, the investment will be paid back in 3 years and 8 months.

Table 4 depicts the cost savings when different ECMs are implemented. The identified energy conservation techniques can be classified into three categories: zero cost (ZC), low cost (LC), and high cost (HC). ECM 1, 2, 3, and 4 are zero-cost strategies that could save up to 11.5% (57,290 kWh/year) of HVAC energy use. The LC measure involves the implementation of occupancy sensors for lighting, resulting in a decrease in energy usage by 96,154 kWh/year.

The high-cost option proposed is to replace the glazing with lower SHGC values, which results in a 6.8% energy savings (34,615 kWh/year). The high-cost endeavours also involve upgrading the existing VRF system with a more efficient inverter-based compressor running on R410A refrigerant. However, as noted in section 3.3, adopting this cutting-edge technology necessitates a full retrofitting of the entire HVAC system, potentially causing substantial disruptions to the building's operations. Therefore, given the exorbitant expense and the impractical interruption to facility usage, this option seems unfeasible in the current scenario. Another alternative is to use natural sunlight energy for lighting near windows from morning to evening. It is possible to consider using light sensors to lower the intensity based on the availability of natural light. Because it reduces direct solar heat, the shading effect can also save a significant amount of energy for HVAC.

Table 4. Summarizing the ECM and its savings

No.	Type	Recommendation	Energy saved (kWh/year)	The percentage saved (%)	The cost saved (OMR)	Payback Period (Year)
1	ZC	Turning off HVAC under no occupancy	25920	5.20	675.00	-
2	ZC	Increase thermostat setting to 24°C	17430	3.50	453.20	-
3	ZC	Closing the main doors to reduce infiltration	6472	1.30	168.20	-
4	ZC	Applying proper maintenance	7470	1.50	194.40	-
5	LC	Lighting control with occupancy sensors	96154	19.30	2,343.00	0.06
6	HC	Applying selected shading on the windows	34615	6.80	900.00	3.8
		Total	246311	37.60	4733.80	

3.7 Application of Nano paint on internal walls

Many researchers have disclosed that Nano paint, which contains nanoparticles, offers several properties that can enhance the thermal performance of buildings and reduce the energy required for cooling. Nano paint can incorporate nanoparticles that reflect infrared radiation, thus reducing heat transfer through walls. Furthermore, Nano paint formulations can be designed to have lower heat absorption properties, meaning the walls absorb less heat from the environment. This helps in keeping the indoor space cooler, thereby reducing the need for air conditioning to maintain comfortable temperatures. While the initial cost of Nano paint may be higher than traditional paint, the long-term energy savings and other benefits often justify the investment (Ahmed & Gharib, 2020; Azemati et al., 2023; Khadraoui & Sriti, 2019).

3.8 CO_2 Emission Reduction

Implementing the proposed solutions to reduce energy consumption can result in a significant decrease in CO_2 emissions. In 2020, Oman's electrical output generated approximately 0.4899 kg of CO_2 equivalent per kilowatt-hour. Therefore, the reduction in CO_2 emissions can be calculated as follows:

CO_2 emissions reduction per year = Energy saved (in kWh/year) × CO_2 emissions factor (in $kgCO_2e/kWh$)

Substituting the values:

CO_2 emissions reduction per year = 246,311 kWh/year × (0.4899 $kgCO_2e/kWh$)

CO_2 emissions reduction ≈ 120.7 metric tons/year

Thus, by saving 246,311 kWh of energy, approximately 120.7 metric tons of CO_2 emissions can be prevented per year.

CONCLUSIONS

The current energy audit revealed a significant opportunity for energy savings that could be quickly realized with small changes to usage patterns, increased occupants' knowledge, and more frequent standardized checkups and servicing. In addition to the energy savings, the study has revealed the comfortable conditions of the facility for the occupants by adjusting and controlling to the optimum conditions. Based on the results of this research, the AKH building primarily expends its electricity on air conditioning, constituting a substantial 67% of its overall energy usage. By putting into practice, the suggested energy conservation techniques (ECTs), it is anticipated that a noteworthy reduction of 37.6% in energy consumption can be achieved. The decision to heed these recommendations ultimately rests with the college campus services and management. Comfort, cost saving and environmental considerations are frequently the motivating reasons for this choice.

RECOMMENDATIONS

Unwanted energy usage and expenditures can be reduced while still preserving indoor air quality and comfort by using energy conservation methods (ECMs) discussed in the current work. Although the objectives of the current work have been met, the following investigations and actions can be carried out for further energy savings.

- Introduce building automation systems (BAS).
- Using modern control approaches: By implementing contemporary control methodologies like neural networks, fuzzy logic, machine learning algorithms, and similar techniques, it is possible to enhance the energy efficiency and overall productivity of VRF systems.
- Utilizing renewable energy: The use of renewable energy is crucial to reducing energy consumption and promoting sustainable energy usage. The location has a lot of potential for solar energy, however, the AKH building doesn't have any renewable energy systems in place. The building's position and geographic setting provide an excellent opportunity to add solar panels, which can help with the structure's energy needs. Investigating the feasibility of harnessing solar energy through the deployment of PV panels will be a forthcoming research endeavour aimed at promoting sustainability goals.
- Transitioning from R22 to R410A as the refrigerant could be a viable option, primarily because it leads to a significant improvement in the Coefficient of Performance (COP) of the refrigeration system. Furthermore, due to the increased efficiency and reduced environmental impact associated with R410A, the system plays a crucial role in advancing sustainability objectives. Given that R410A operates at significantly higher pressures than R22, transitioning the entire air conditioning system may require substantial initial investment and disruptions in the building's operation. Therefore, a thorough investigation is necessary regarding the relocation of both staff and occupants within the facility.
- Integrating LEDs with a compatible LED dimmer switch also presents a significant energy-saving opportunity. Dimmers effectively regulate lighting levels in facilities, fostering a warm and comfortable atmosphere while concurrently reducing energy consumption. This dual benefit not only enhances ambience but also promotes sustainability in lighting solutions.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

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