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Guidelines for data collection on energy performance of higher-education buildings in Egypt: a case study

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ABSTRACT

Reliable energy analysis of buildings relies heavily on high-quality data leading to proper indicators. Previous studies have highlighted the importance of data quality in analyzing energy usage in residential and non-residential buildings in order to transform declarations to actions, optimise energy efficiency policies and monitor progress and failures in countries. Collected data must adhere to national and international standards for energy performance in buildings. This study aims to provide practical guidelines for effectively collecting and preparing data suitable for evaluating energy performance in Egyptian higher-education (HE) buildings. The guidelines are developed based on a comprehensive case study, considering data availability in typical educational facilities. Architectural and civil engineering drawings, construction specifications, and occupancy details are accessible. However, actual monthly electrical and natural gas consumption data for individual buildings are lacking. To address this, the study proposes the creation of detailed datasheets for each building, encompassing all energy sources and their electrical and power specifications, such as equipment, machinery, and HVAC systems. These datasheets were utilized to calculate energy consumption and energy usage indicators (EUI). The findings demonstrate that the datasheets enable adequate assessment of energy usage in various spaces within educational buildings, including staff rooms, lecture halls, and laboratories. This facilitates the identification of areas in need of targeted energy efficiency improvements. Notably, the study reveals that electricity consumption in the Faculty of Engineering building is significantly influenced by PCs, laboratories, lighting, and air conditioning.

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KEYWORDS Building’s energy efficiency; higher educational building; data collection; data analysis

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Introduction

Background

In line with the urgent demand for ensuring sustainable development and abiding sustainability requirements, energy analysis of buildings has become a global interesting and attractive application for governments, energy-related businesses and even consumers [1–19]. Since the building industry is responsible for 20–40% of worldwide energy use [14], the overall goal from the effort of all stockholders is reducing energy consumption and increasing the energy efficiency of both new and old buildings. Throughout the last three decades, the scientific community has paid special focus on energy management in buildings in compliance with the Kyoto Protocols and recently the United Nations' SDGs (Sustainable Development Goals). Several approaches are explored such as but not limited to presenting new architectural design ideas, integration of novel materials, monitoring, and control of energy efficiency in buildings, etc. Improving energy efficiency in educational buildings entails cutting operational expenses, increasing sustainable development, and consuming less energy. Education buildings present a significant contribution to energy consumption, as compared to others [1], educational buildings have significant energy use. University campuses may resemble small cities as they should provide space for various activities with laboratories, educational rooms, libraries, office buildings, and many other student facility areas of different features and energy needs [1]. Moreover, the important local socioeconomic effect of university campuses in cities is usually a demonstration of the development potential. Analyzing energy use and understanding its characteristics in university buildings is the only way to introduce control measures on a significant scale [2] and guidance to improving energy efficiency in buildings and cities.

State of art

Different initiatives are reported aiming at evaluating the energy consumption in educational buildings and introducing energy saving strategies to increase energy efficiency. A study by Ma et al [3] analyzed the energy status and energy saving measures of several universities based on building energy consumption and compared the data including energy consumption per unit area, electric energy consumption per unit area, energy consumption per capita, electric energy consumption per capita and carbon emission per capita. The characteristics of building energy consumption in the universities were suggested to provide the basis for energy saving measures and the development of carbon reduction plan. On the other side, Guangdong Province's colleges and universities' energy usage in China, including the use of electricity, gas, water and cooling energy, was studied by Zhou et al.

[4] and the results showed their differences in unit energy use varying for different university types and nature. Energy consumption was studied in campuses in Mexico by Escobedo et al. [5] and China [6] and the energy consumption was predicted for the buildings and facilities together with its related greenhouse gas emissions and different scenarios for energy-consumption reduction and energy efficient technologies were developed to increase energy efficiency. Similar methodologies were used for energy planning by Guan et al. [7].

Detailed auditing and identification of lighting used materials and energy consumption for cooling load resulted suggestions that can reduce the amount of electrical energy used by up to 35.3% and to increase the A/C units' efficiency up to 31% by a study by Sait [8] on an educational building north of Jeddah, Saudi Arabia. Strategies for efficient energy consumption were developed by Sekki et al. [9] in a study on Southern Finland university buildings. The study [9] showed that, although the climate was cold, primary power use was higher than heating energy usage in educational buildings constructed in the 2000s. Analysis of the features of various building types' energy usage on campuses of higher education conducted by Khoshbakth et al. [10] showed that research buildings have the highest value, 216 kWh/m^2/year, among Australia's 80 university buildings, while the most valuable structures are academic office buildings, 137 kWh/m^2/year.

Marc Medrano et al. [11] presented a case study in Spain to assess conventional and renewable energy consumption of university buildings. The study proposed a system which tackles the problem of data collection in university buildings. The proposed database covered data on the building's shape, data on the hourly and quarter-hourly consumption of power and gas, operational information, and the effect of weather to assist universities in creating nearly zero-energy buildings. Also, another study by Ferrari et al. [12] evaluated the electrical energy performance of tertiary buildings and devised a system for the study of power consumption data in older and already existing buildings. The study defined a number of Electricity Consumption Indexes (ECIs). This can be used to evaluate how well different buildings perform. The study also provided actual electricity consumption data, measured in 1-hour stages for 2 years split into three specific periods: medium and long term, normal seasonal weeks, and monthly.

Hong et al. [13] presented a review of literature covering various strategies used to implement Net Zero Energy Building (nZEB) for the last 10 years, using passive and active strategies and examined an energy use model for one university in Korea. In line with the life cycle of a building (that is, the initial and use phases of a building's life cycle), analysis was made by integrating passive and active strategies and real-time monitoring of the energy performance and the analysis of the types and quantities of energy consumed in campus buildings was used to develop advanced strategies for nZEB. Yildiz et al. [14] compared historical energy consumption of different types of buildings over a 10-year period in Çağış Campus of Balikesir University and the results showed that the university hospital is the largest energy user in comparison to other structures. In contrast, between 2008 and 2019, the Rectorate, the Faculty of Science and Letters, the Medico Social Building, and the Faculty of Engineering and Architecture accounted for about 70% of the total energy consumption on the Çağış Campus. The concluded results from the study were used to determine the priorities for retrofitting. A study by Fitriani et al [15] was carried out in order to provide more accurate predictions of the performance of educational buildings under better scenarios, and an energy analysis model integrating Building Information Modeling (BIM) was developed. An existing Palembang building's energy usage was contrasted with the Indonesian Standard for educational buildings. The energy use intensity (EUI) of the building was determined by calculating its electrical consumption, and it was then compared to the SNI 03–6196–2000 norm. Benchmark criteria in accordance with the ASHRAE 90.1 (2019 & 2022) [16] and a three-dimensional model was produced by the BIM Revit tool to restructure the building object.

Generally, actual monthly consumption figures for natural gas and electricity for most of these studies were either developed by proposed methodologies using spreadsheet macros [13] or directly accessible and available from the campus management [15]. After the publication of the Energy Performance of Buildings directive [17], interest in energy efficiency has increased. Detailed studies for analysis of the amount of electricity used in academic buildings is given by [18,19], the studies emphasized the significance of availability of electric consumption data and in-voices for educational buildings. Studies on energy consumption in schools (high, secondary and primary) showed that the electricity consumption of school buildings is largely affected by lighting and air conditioning. Actual energy consumptions in buildings were reported, on average, 2.5 times higher than predictions during the design stage, which is known as the performance gap and the need for actual hourly lighting and plug load consumption profile was emphasized [20].

Despite the growing interest and awareness among Egyptian building and construction sector of the sustainable development goals and the emphasis on energy efficiency in buildings for both economic and sustainability reasons, limited studies have addressed these issues. Moreover, there is a great lack of codes and regulations related to the energy efficiency of educational buildings and other governmental buildings, no practice to evaluate energy usage in buildings, and there is no solid energy audit system and safe indoor air quality standard for Egyptian buildings. These regulations and codes may be developed from international standard specifications and codes, the most widely adopted internationally being ASHRAE. Therefore, this study is planned to review the current regulations and research status in Egypt, compare it to other countries and hence proposing guidelines that would help and pave the road toward monitoring energy usage in Egyptian higher education buildings (as a model that could be adapted for other organizational buildings). After reviewing the Egyptian status and identifying the real on-ground challenges that make it difficult to monitor energy usage, a series of steps are proposed to overcome the challenges of collecting and analyzing the data.

Energy efficiency in educational buildings in Egypt

Limited initiatives and efforts are reported during the last few years aiming at studying energy efficiency in educational buildings in Egypt. The published information on the educational buildings energy consumptions in Egypt is somewhat limited and mostly published by international agencies. According to a report by the United Nations Development Programme (UNDP) [21], buildings in Egypt account for 30–40% of the country's total energy consumption, and the education sector is one of the main consumers of energy in the building sector, due to its complex functions by providing space for various activities and disciplines. A study conducted in 2019 by the European Bank for Reconstruction and Development (EBRD) [22] estimated that energy consumption in Egyptian schools could be lowered by as much as 30% by means of the execution of energy-efficient measures. The study found that the main sources of energy consumption in schools were lighting, air conditioning, and water heating. Another study published in 2018 [23] analyzed the energy performance of a primary school building in Egypt and found that the building's energy consumption was higher than the recommended levels set by the Egyptian Energy Conservation Code. The study recommended the implementation of energy efficient measures, such as improving insulation, optimizing HVAC systems, and using renewable energy sources, to reduce the building's energy consumption.

The National Program for Energy Efficiency in Buildings (NPEEB) was launched in 2012 to improve energy efficiency in buildings across various sectors, including education. The initiative offers building owners financial assistance and technical support to help them implement energy-efficient solutions [24]; Chapter 10 of the Egyptian energy efficiency building code lacks a specific ceiling on the final energy consumption per square meter, but only necessitates a thorough building performance analysis using meteorological data spanning an entire year. By establishing such a limit, it would be ensured that a defined benchmark is used to distinguish between energy-efficient and non-efficient buildings. The Green School Initiative aims to promote sustainable practices in schools, including energy efficiency. It provides training and support to teachers and staff to implement energy efficient practices, such as reducing energy consumption, optimizing HVAC systems, and using renewable energy sources [25]. Between 2005 and 2009, Egypt introduced building energy-efficiency codes (BEECs) to enhance the energy efficiency of buildings, both commercial and residential. However, these codes were voluntary and haven't met any mandatory actions, obligations, or policies with incentives or penalties to encourage the adoption of BEECs in Egypt.

Thus, a building energy efficiency roadmap in Egypt is required to be developed and to be extended to cover educational buildings as well. This roadmap shall include training and awareness, incentives and penalties, monitoring and evaluation and continuous improvement. By following this roadmap, Egypt can enhance the adoption and enforcement of building energy efficiency codes, leading to improved energy performance and sustainability in the country's buildings. Some studies have recently addressed the data collection challenges [25,26]. A case study of a governmental office building used for educational purposes (the Mechanical Engineering Department building at the Faculty of Engineering Campus of Ain Shams University) was investigated by Fady Emil and Aya Diab [26]; The mechanical systems utilized to condition the building utilizing Energy Plus and a variety of passive and active retrofitting solutions to the building envelope were used to analyze the energy needs. Many retrofitting strategies and energy saving techniques have been assessed and compared to reach an optimized building envelope with minimum energy needs (energy rationalization). The total savings ranged between 20% and 50% based on the suggested retrofitting strategies. Another study has been conducted by Elshamy et al [27] to explore the challenges contesting the strategy for effectively supplying Egypt with renewable and clean energy that achieves 42% of its total electricity. The main barriers have been identified as resulting from the built environment, climatic conditions, operation and maintenance requirements, and other technical issues during the building's operational stage. Though the work included the whole building stoke in Egypt, the challenges and barriers surveyed through the work included the university buildings. The study also investigated some solutions to tackle those barriers. The study showed that there is an urgent need for generating effective energy-efficiency (EE) codes for buildings. Though building energy-efficiency codes (BEECs) have been initiated in Egypt between 2005 and 2009, these codes have not met any compulsory actions to execute them, and no training for actors in the building chain or encouragement policies have been implemented. The study used TRNSYS and ANSYS software tools and the data collected for weather from the weather station located on the BUE Campus to examine the technological viability of applying solar-thermal cooling and wind energy systems share in Egyptian buildings' energy supply mix. It was found that using solar-thermal cooling located on the rooftop and using the energy-ball wind turbine in a conventional low-rise building present prospects for renewable energy integration in the energy mix for educational and residential applications. While in high-rise buildings in Egypt, if three horizontal wind turbines (HAWTs) are mounted on each roof in the suggested staggered configuration, the total power produced by wind turbines per building might be as high as 6 kW. The authors concluded that a systematic analysis of the true use and integration of renewables into Egypt's built environment should begin with energy efficiency in buildings.

Objective of this study

The previous background and state of art illustrates that one of the most crucial problems facing the implementation of energy-efficiency codes in Egypt is the absence of enough information on the energy consumption of university buildings, as well as other governmental buildings. University and educational buildings are characterized by their growing need for energy on college campuses, resulting from technology advances and energy consuming laboratory and computing facilities [5,6,10,12,13,15]. Accordingly, there is a need for more research and data on educational building energy consumption in Egypt, as well as greater efforts to promote and implement energy-efficient measures in schools. However, the implementation is challenged by the absence of a clear road for data collection as the first step for meaningful data analysis. Therefore, the main objective of this study is to provide simple guidelines for collecting energy performance data and presenting it in an appropriate form for data analysis. Those guidelines are developed based on a case study of a university faculty of engineering building. The study aims at identifying the needed analysis parameters and the type of data needed to quantify those parameters in line with recommended codes and/or standards. Stakeholders and relevant experts who wish to compare the energy performance of new construction to that of the current building stock will find the results useful.

Therefore, following the introduction presented in section 1, Section 2 presents a comprehensive review of international codes and standards for energy performance in buildings. This section aims to provide an insight into establishing the guideline by understanding the influence of energy-related decision-making in building design, construction, and operation. Section 3 describes the research methods and procedures applied in this study to collect energy performance data. It describes the steps followed to gather relevant information, including data collection methodology and any specific considerations taken during the process. Moving forward, Section 4 focuses on presenting how the energy consumption and heat gain in buildings was calculated. It elaborates on the techniques and measurements used to quantify energy performance. In Section 5, the paper presents the results obtained after the data collection which includes an analysis of the energy consumption and heat gain patterns observed in the building. Finally, Section 6 concludes the paper by summarizing the key findings derived from the data collection process. It highlights the implications of the results, discusses their relevance to the objective of the study, and offers insights into potential areas for further investigation.

Review of international codes and standards for buildings

Buildings that use less energy are advantageous for the environment and the economy, due to increasing carbon emissions from usage of conventional fuels. By promoting innovative energy-efficient technology, they also assist in highlighting economic prospects for business and industry. Energy efficiency should be encouraged and mandated since it helps prevent climate change, pollution, and may affect national security, as energy is significant to all nations. Energy codes and standards are essential because they set the minimal specifications for building and designing in an energy-efficient manner. They offer defined specifications for brand-new structures, goods, and improvements.

Exploring specific codes and standards for lighting, ventilation, and other relevant areas while recognizing the laws and international conventions that regulate them can help in understanding the difference between an energy code and an energy standard. Codes are established in language that is mandatory and enforceable and governs how structures must be designed or function. Energy codes are adopted and implemented by states or municipal governments. Standards specify how structures should be built to save energy efficiently.

For standardization, leaders in the field have developed standards for evaluating buildings' energy performance. However, the majority assume steady state working conditions. Countries, in addition, have developed their own building energy-efficiency codes (BEECs). National organizations like the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) publish them. Although they are not required, they do serve as national suggestions with some regional climatic variation. When state and municipal governments adopt standards as their energy code, they become binding. Energy standards are frequently used by state and municipal governments as the technical foundation for creating their energy regulations. It is simple for authorities to include the provision of energy standards directly into their laws or regulations because some energy standards are expressed in language that is mandatory and enforceable.

Energy codes and standards

The main specific energy codes and standards which are of concern for buildings are:

- The International Energy Conservation Code (IECC) [28].
- ASHRAE Standard 90.1 (Energy Standard for Buildings Except for Low-Rise Residential Buildings) [16].
- ASHRAE Standard 55 (Thermal Environment Conditions for Human Occupancy) [29].
- ASHRAE Standard 62 .1 (Ventilation for Acceptable Indoor Air Quality) [30].
- ASHRAE Design Guidance for Education Facilities [31].

The international energy conservation code (IECC)

The International Energy Conservation Code (IECC) [28] has been established by the International Code Council (ICC) as a model for other authorities to use when defining their codes. By using modern materials and methods, efficient mechanical, lighting, and envelope design, it promotes energy conservation. It establishes various temperature zones to enable a good localization of the model, which may then be further customized by state and municipal governments to represent local building customs.

ASHRAE standard 90.1

The American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) is a professional organization that publishes various standards. In terms of buildings, two are particularly significant; Commercial buildings should adhere to ASHRAE 90.1 [16], and residential buildings should adhere to ASHRAE 90.2 [32]. These standards address numerous architectural elements and systems that have an impact on energy use. This covers the exterior of the building, motors, lighting, water heating, HVAC components, and power. Each is explained in a technical part that includes broad specifications and laws that must be followed. Additionally, certain sections contain paths for mandatory compliance. Building designers can make compromises under Standard 90.1, and the method used to assess the results is known as the Energy Cost Budget Method (ECB). ASHRAE Standard 90.1 is used by many states, municipalities, and other agencies as the energy code requirements for buildings [16]. The original standard was named ASHRAE 90 in 1975 and was updated gradually with new technologies to a continuous maintenance schedule with major publications occurring every three years, so it is a renowned energy standard. It is not a code and only applies as code when a government body makes ASHRAE 90.1 a requirement through legislation. It can be acknowledged that ASHRAE 90.1 serves as both the international standard and the baseline for energy codes and standards for commercial buildings in the United States. The design of buildings by engineers to meet energy efficiency targets is outlined in ASHRAE Standard 90.1 [16]. The minimal energy efficiency requirements for the design and construction of new sites, buildings, and their systems, as well as new systems and equipment in existing buildings, are provided in detail. It also includes criteria for determining compliance with these requirements. The minimal energy efficiency requirements for the design and construction of new sites, buildings, and their systems, as well as new systems and equipment in existing buildings, are provided in detail. It also includes criteria for determining compliance with these requirements. To implement the standard requirements and to raise the energy performance for buildings, model codes are developed based on the standards. The most important model codes being IECC, LEED, BREAM, etc. Due to the rapid advancement of energy technology and the need to promote sustainable buildings while reducing energy prices, the standard has been subjected to continuous maintenance and updates. For example, the ASHRAE 90.1–2010 edition achieved 30% energy savings compared to the previous 2004 edition, while ASHRAE 90.1–2013 reflects various innovations and more efficient technologies that make it possible for buildings to consume less energy. The 2019 edition of Standard 90.1 incorporates over 100 addenda to the 2016 edition and includes numerous energy-saving measures. Significant modifications were added to the 2022 versions of ASHRAE/IES Standard 90.1, with respect to the whole-building performance routes, new appendices were included, and the wording used in the Energy Cost Budget Method (ECBM) and Performance Rating Method (PRM) were altered. The update of the Building Performance Factors (BPFs), which shows the necessary improvement in regulated energy usage relative to the baseline, is one of the more significant adjustments. About 60% of the BPFs have loosened as a result of a new, more precise method, which is used to produce the Performance Cost Index Target (PCIt) [16].

The purpose of ASHRAE 90.1, as described by the standard itself, is 'to establish the minimum energy efficiency requirements of buildings, other than low rise buildings, through design, construction, operation, maintenance and utilization of onsite renewable energy resources'. The goal is to set minimum energy-efficient standards for new building design, construction, operation, and maintenance, portions of buildings, new systems in existing buildings, new equipment or building systems. The primary features of ASHRAE Standard 90.1 are:

- The building's maximum lighting power allowance (W/ft) is determined.
- There are defined minimum insulating criteria.
- Areas where precautions must be taken to prevent air leakage are specified.

- Control of the interior and outdoor illumination is necessary.
- Service water heating and HVAC equipment must meet minimum energy efficiency standards.

There are specific steps suggested to be applied to compliance with ASHRAE 90.1 [16] which are briefly described as:

(1) Determine the building type and climate zone.
(2) Establish the building envelope requirements (the requirements for insulation, windows, doors, and other components of the building envelope).
(3) Determine the HVAC system requirements (HVAC system design, including efficiency standards for equipment and controls).
(4) Determine the lighting requirements (requirements for lighting power density and controls).
(5) Consider other energy uses.
(6) Conduct energy modeling: Energy modeling is required to demonstrate compliance with the standard. The modeling process involves simulating the energy performance of the building design to determine if it meets the minimum requirements of the standard.
(7) Submit documentation.

ASHRAE standard 55

The 'Thermal Environment Conditions for Human Occupancy' is a section of ASHRAE Standard 55–2004 [29] aims to create thermal conditions that are comfortable for 80% of the inhabitants. The standard considers environmental variables such as airflow, humidity, thermal radiation, and temperature. Also taken into consideration are individual factors, particularly attire, and activity in the area. Regarding humidity and temperature, both winter and summer circumstances are discussed. The energy efficiency program must take these thermal comfort requirements into account. Energy optimization includes adjusting HVAC set points; however, it is unacceptable to save energy at the expense of compliance. Building management technologies are particularly good at increasing energy efficiency while keeping occupant comfort levels at acceptable levels. Both indoor air quality and thermal comfort are included under the Leadership in Energy and Environmental Design (LEED) Green Building grading system's indoor environmental quality component (IEQ).

ASHRAE standard 62.1

ASHRAE Standard 62.1 [30] aims to reduce the possibility of harmful health impacts by defining minimal ventilation rates and indoor air quality that will be acceptable to human occupiers. A wide variety of pollutants, including those released by industrial activities, those found in carpets and furniture, physical pollutants like dust and fibers, and biological pollutants like those inhaled by building occupants, can have an impact on air quality. It applies to all indoor or enclosed locations that humans may occupy unless larger volumes of ventilation than this norm are required by other applicable standards and requirements.

ASHRAE design guidance for education facilities

ASHRAE Design Guidance for Education Facilities [31] was developed by ASHRAE Technical Committee (TC) 9.7, Educational Facilities to offer guidance to owners, operators, designers, and professional service providers on how to best implement indoor air quality (IAQ) improvements, including risk mitigation strategies, in educational facilities. It will also help facilitate discussion between designers and stakeholders, identify minimum recommendations, and discuss further considerations to improve IAQ and reduce the transmission risk of infectious pathogens and other contaminants of concern. The guidance should be used to prioritize decisions related to heating, ventilating, and air-conditioning (HVAC) system design and operation for existing facilities (commissioning, maintenance, improvement, and retrofit projects) and new facilities to improve indoor air quality while limiting energy consumption.

Air quality: the ventilation rate procedure (VRP) and indoor air quality procedure (IAQP)

Two methods [30] that could be applied to deal with Indoor Air Quality (IAQ) are the Indoor Air Quality Procedure (VRP) and the Ventilation Rate Procedure (IAQP). It's important to keep in mind that just one of these approaches can be used. The Ventilation Rate Proce-dure (VRP) involves supplying the space with ventilation air of the specified quality and at least the given quantity to attain acceptable air quality. This technique establishes an outdoor air quality standard and a method for determining whether outdoor air is suitable for use in ventilation. To regulate the number of contaminants, it may be required to treat the outdoor air. The standard is based on the ventilation rate. The standard assumes that the results will be satisfactory indoor air quality as long as the outdoor air is of appropriate quality and is available in sufficient quantities. For residential houses, commercial buildings like offices, institutions like schools and hospitals, industrial spaces like factories, and spaces for vehicles like parking garages, minimum ventilation rates are required. According to the Indoor Air Quality Procedure (IAQP), known and specific contaminants must be controlled to achieve acceptable air quality in the area. In comparison to the Ventilation Rate Procedure, this poses a very different issue. The VRP assumes that the indoor air quality will be accepted if the external air quality is satisfactory and the rate of ventilation to the space complies with the norm. On the other side, the IAQP procedure mandates that you demonstrate that all known pollutants of concern are constrained to acceptable levels. The IAQP is less frequently employed, and the VRP is more frequently chosen by designers as a result of the burden of evidence [30].

While the VRP handles the issue indirectly by dictating outdoor air quality and ventilation rates, the IAQP is sometimes referred to as a direct solution. Using a performance-oriented design strategy is necessary for IAQP implementation. This means that the designers must make sure that the structure's ventilation systems and certain contaminants are maintained at concentrations that do not exceed predetermined limitations. These re-strictions could be established by precise numbers as well as a subjective assessment of what building inhabitants and/or visitors deem to be acceptable.

Energy efficiency offset control schemes for advanced indoor air quality (IAQ) handles expected higher energy usage with the increase of more ventilation air and suggests that the best approach for energy efficiency during the period of increased ventilation rates is to focus efforts on unoccupied times.

Leadership in energy and environmental design (LEED)

Leadership in Energy and Environmental Design (LEED) is a certification program that offers a framework for creating, managing, and maintaining green communities and buildings. It was developed by the U.S. Green Building Council (USGBC) and is recognized worldwide as a symbol of sustainability and environmental responsibility. The LEED certification is achieved through a points-based system that evaluates a building or community's environmental performance. LEED evaluates and certifies energy efficiency, as a key aspect of sustainability.

Research methods and procedures for collecting energy performance data

The previous sections have highlighted the importance of the availability of data monitoring energy usage in education buildings for either analyzing energy efficiency or implementing energy solutions or retrofitting acts that would lead to enhanced energy efficiency. Though some educational buildings in Egypt, such as The American University in Cairo Fifth Settlement, uses BMS technology and can collect data (Temperature for each area indoors and outdoors, electrical consumption, heat dissipation, … etc., daily, monthly, and annually) which enables monitoring energy consumption, the majority of education buildings and university campuses do not have an embedded system for collecting or monitoring actual monthly energy consumption data for individual buildings.

The procedures for collecting and analyzing the energy performance of buildings are based on defining energy demand (which varies according to the building's function) and are also affected by climatic conditions, seasons, outdoor temperatures, etc. This is followed by determining the amount of energy used or consumed. The energy analysis of buildings starts with data collection based on calculations and measurements followed by statistical analysis. Also, the goal of energy consumption modeling is to ascertain the energy needs in relation to input parameters. Models can be used to assess the needs for energy supply as well as fluctuations in consumer demand with or without the integration, upgrading, or addition of sustainable energy technologies [21].

Both simple and complex statistical techniques can be used to compare energy consumption [3], where simple refers to using database/tool and complex refers to using more advanced and specialized software tools. The most popular approach in literature uses basic descriptive statistics based on relative performance indicators by normalizing energy usage per floor area and adjusting to climate data. The energy use intensity (EUI) refers to as the annual energy consumption per square meter is a useful benchmark to evaluate the Electrical Consumption between buildings under similar categories. The entire quantity of all energy utilized in a year is indicated by the energy usage intensity indicator (kWh/m^2/year), which is employed as an assessment tool in the majority of countries (fuel oil, natural gas, and electricity). To compute the energy consumption value per unit of base area, divide the total energy consumed in kWh by the building's floor area. This yields the energy use intensity indicator [33].

In view of the previous literature review on research studies internationally and locally in Egypt, procedures for data collection in high engineering education buildings are adopted in this work.

The step-by-step procedure for energy analysis of the studied educational buildings is as follows:

(1) Choosing the targeted building in each university.
(2) Recording all energy consuming resources in the building/per floor and per room. Followed by a full assembly of information on energy use in the building.
(3) Performing a thorough analysis based on the amount of energy used per person and per square meter.
(4) Comparison based on each space energy use intensity indication.
(5) Introducing a simulation/modeling analysis to enrich the results from the data collection.

(6) Comparing energy consumption of the chosen buildings with buildings from other countries as published in the literature.

In future work, the remaining two following tasks shall be continued:

(1) Validating the analysis by physical measurements using suitable tools.
(2) Comparing energy consumption of the chosen buildings with ASHRAE energy model calibration guideline or ISO 13,790 (currently being updated to ISO 50,016).
(3) Proposing suitable solutions to reduce energy consumption in spaces with high energy indices. (This is not part of this work)

The required data includes actual monthly energy use, on-site inspections, and mechanical and architectural project drawings. Air heating from ventilation and space heating are examples of heating usage. Electricity consumption covers lighting, cooling, and all kinds of electrical equipment. However, in real life in typical Egyptian educational buildings or university campuses, actual monthly energy consumption data are not available for individual buildings in the main campus of universities. Therefore, alternative methods should be developed based on electrical equipment and machinery included in the studied envelope, HVAC cooling capacity and power consumption, etc.

In the current study, an educational building, representing typical engineering–higher education facilities (the Faculty of Engineering Building A in the British University in Egypt (BUE)), is used as sample for showing type of data needed for energy analysis. The specifications and the location of the building are listed in Table (1) and Figure (1). Samples of the architecture and interior design of the building are shown in Figure (2).

Since the inspected building is owned by the university, all applicable procedures were followed, including requesting authorization to access the facilities for data gathering within a predetermined time frame to prevent any disruption to academic operations. Moreover, the building utility data were requested from the campus management department, such as AutoCAD drawings and so on. The following functions are considered during the analysis.

The data were collected from an educational building in the British University in Egypt – private university. The type of spaces/rooms in the

Table 1. Chosen building specifications.

Building Specs.	BUE
Location	Building A (Engineering), BUE main Campus, El-Shouroq city (30.11867, 31.60822).
Total land area (m^2)	3775
No. of floors	1 basement + 3 floors + roof
No. of individual spaces	125

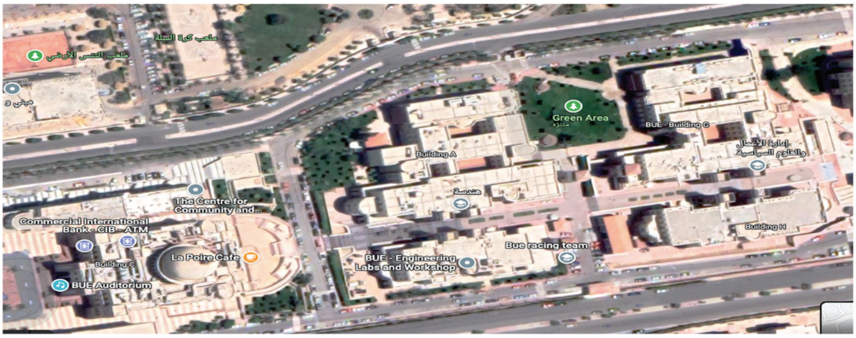


Figure 1. Google map for the BUE building location.

Figure 2. Samples of the architecture and interior designs of the BUE building.

building was identified based on the type of usage/operation (staff room, classroom, etc.).

The number of occupants was assumed based on the available data which is affected by the time/day.

The collected data includes quantity and type of lighting systems, available equipment and their power consumption, HVAC cooling capacity and power consumption, and area of each space/room including the fenestration area.

A database is generated to include all the collected data and apply the required calculations through the analysis stage (not included in this work). The database has been designed to work as a program where there are inputs, assumptions and outputs with supported analysis and graphs. The design can accommodate variables of different issues such as the building floors, type of utilization, weather, time of the year, etc. The data collection methodologies depend on the strategies described in the following flow diagrams, Figures 3 and 4.

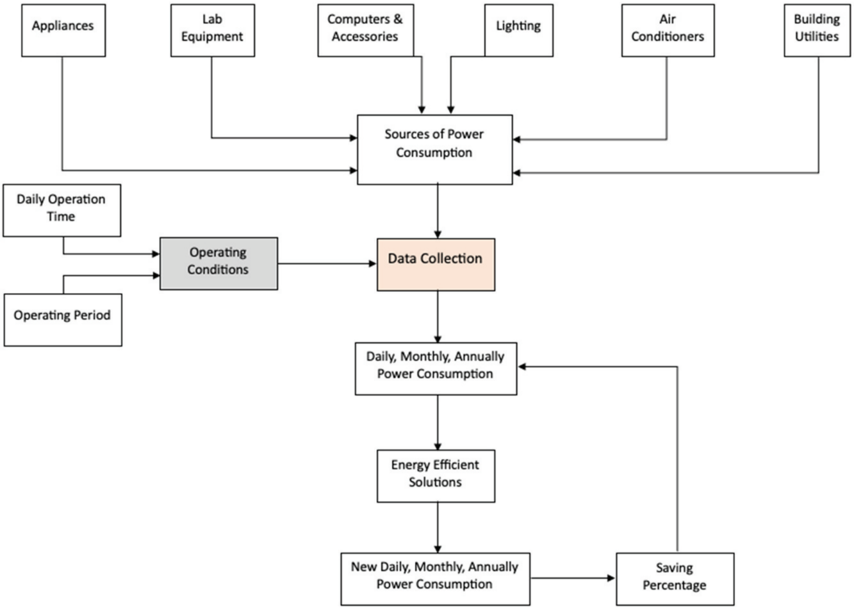


Figure 3. Power Consumption Data Sheet Flowchart.

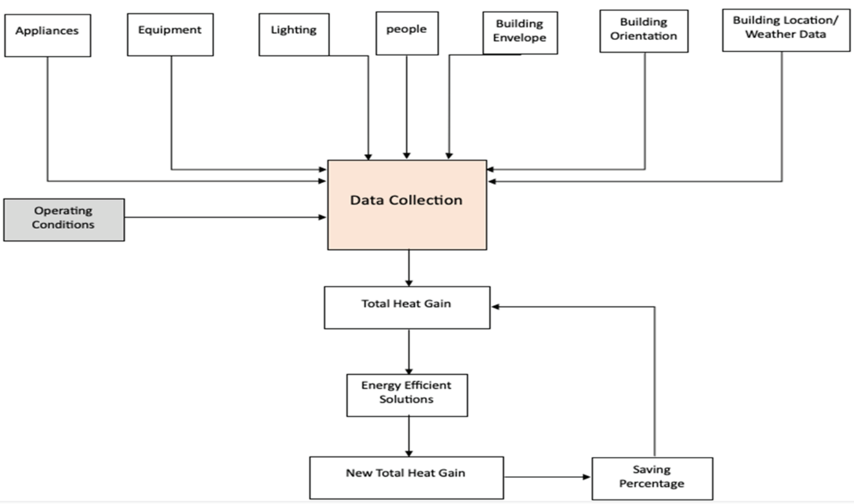


Figure 4. Heat gain data sheet flowchart.

Collecting data to calculate the energy consumption in the buildings

The electrical power consumption

The power consumption of all equipment is obtained by checking the manuals of each equipment, reading the energy label on the back/side, or searching on the internet. The number of operating hours for each equipment has been obtained individually from the user, based on operating schedules. The unknown equipment consumption is assumed by the team according to the function of the equipment and the logical time frame. The power obtained from manuals, or the internet is rated as maximum power, while the power consumption of all equipment is a result of equipment operation. At this stage, it was not measured but assumed to be related to the rated power and was calculated according to the following equation used to predict the energy consumption:

$$Energy = Power\ x\ Time \qquad \text{eq.(1)}$$

Heat gain considerations

The equations used in heat gain calculations are retrieved from cooling and heating load estimation by Trane using '1997 ASHRAE Handbook' [34].

Conduction through surfaces

Heat is transferred through solids including walls, roofs, floors, ceilings, windows, and skylights by conduction. Conduction is the natural process by which heat moves from a warmer to a colder temperature. The air temperature outside is usually higher than the air temperature inside when determining the maximum cooling load for a given space. The most typical ways that conduction heat enters a space are through the windows, external walls, and roof. The area, total heat transfer coefficient, and dry-bulb temperature difference between the two sides of the surface all affect the amount of heat transferred through a shaded external surface. The following formula is used to predict the heat gain through conduction:

$$Q = U\ x\ A\ x\ \Delta T \qquad \text{eq.(2)}$$

where Q = heat gain by conduction [W], U = overall heat-transfer coefficient [W/m2 .°K], A = area of the conduction surface [m2], and ΔT = dry-bulb temperature difference through the surface [°C].

Heat generated by people

The heat produced by humans exceeds what is required to keep their bodies warm. Sensible and latent heat from this excess heat is released into the surrounding atmosphere. The body releases different amounts of heat depending on factors including age, gender, physical size, type of clothing, and degree of physical activity. The following table is taken from the Fundamentals section of the 1997 ASHRAE Handbook. It takes into account the average sensible and latent heat gains per individual depending on their degree of physical activity. The heat gains are modified to reflect the typical distribution of children, women, and men in each kind of space.

The following formulae are used to project the sensible and latent heat gains from human occupants in the space:

$$QS = number\ of\ people\ x\ sensible\ heat\ gain/person\ x\ CLF \qquad \text{eq.(3)}$$

$$QL = number\ of\ people\ x\ latent\ heat\ gain/person \qquad \text{eq.(4)}$$

where QS = sensible heat gain [W], QL = latent heat gain [W], CLF = cooling load factor, and CLF is the space's ability to absorb and store heat is taken into consideration.

The walls, floor, ceiling, and furniture in the room absorb and store some of the sensible heat that people produce, which is then released later. As a result, there may be a temporal lag in the space between the time the sensible heat is created and the time it actually contributes to the cooling load of the space, similar to in the case of heat transfer through an external wall. The construction of the internal walls in the space, the kind of floor covering, the total number of hours that the space is occupied, and the amount of time since the people entered the space all affect the value of the Cooling Load Factor (CLF) for heat gain from people. Approximated schedules for personnel, lighting, and equipment should be created in order to determine the internal loads.

Heat gain from lighting

One major source of the cooling load in space is the heat produced by the light. Furthermore, to account for the additional heat produced by the ballast, an additional 20% is added to the lighting heat gain when estimating the heat gain produced by fluorescent light.

The following formula is used to calculate the heat gain from lighting:

$$Q = Power\ x\ ballastfactor\ x\ CLF \qquad \text{eq.(5)}$$

where Q = sensible heat gain [W], power = power of lights [W], ballast factor = 1.2, CLF = cooling load factor

Data collection results

The building is divided into floors and different spaces which include all types of activities, i.e.: classroom, office, bathroom, IT room, etc., each of these spaces include different types of devices that have specific operation time, furthermore each venue has different number of people according to its space and the activities to be conducted in it. The time, in the day, the month and the season were considered in the design and calculations based on assumption. To evaluate the energy consumption in the building, some assumptions are made by the team to reflect the real case. Daily occupation assumptions: lecture halls and classrooms are occupied by 50% from Sundays to Wednesdays, 37.5% on Thursdays, 30% on Saturdays and 0% on Fridays, while staff rooms are occupied by 100% from Sundays to Wednesdays, 75% on Thursdays, 60% on Saturdays and 0% on Fridays. Seasonal occupation assumptions: full load occupation from 16th of September to 15th of June, 10% occupation in lecture halls and classrooms, and 50% occupation in staff rooms from 16th of June to 15th of September.

Electrical consumption data analysis

After gathering the data of each venue in the engineering building, Pie chart presentations were produced to visualize the percentage of power consumption from different devices as shown in Figure 5(a–e). In Figure 5a, for the device's consumption in the offices, the pc power consumption has the highest percentage of 42.71%, on the other hand, the highest power consumption in the lectures and tutorial venues shown in Figure 5b is due to lighting with percentage of 48.59%. The Buildings in the British university in Egypt each contain a room for the servers that must operate all day long, thus it shows a percentage consumption of 90.41%. The lowest power consumption in all venues is due to firefighting alarms with percentages of 0.13%, 0.26% and 0.13%. Several labs are in the engineering building which serve the different majors in Engineering. It is shown from Figure 5 that the simulation labs consume more energy (41.14%) than other labs, this is because most PCs are left working for long time, agreeing with previous results reported internationally [5,6,10,12,13,15]. As for the washing rooms, the water heater has the highest consumption 75.61%.

Figure 6(a–c) shows the monthly power consumption for Staff offices, lecture & Tutorial Rooms & labs which have the highest power consumption in the winter and summer semesters and the lowest in the summer break months as their usage solely dependent on the teaching. The building utilities monthly power consumption in Figure 6d shows variation mainly due to the official vacations in Egypt, similarly the washing rooms monthly power consumption shows the same trend. The air conditioning monthly consumption was analyzed separately and displayed the highest peaks in the summer months in Egypt which are from half of June to the first week in November, the rest of the year the sum of AC is used for heating and cooling in specific venues such as cooling in lecture halls and water heating in server rooms as

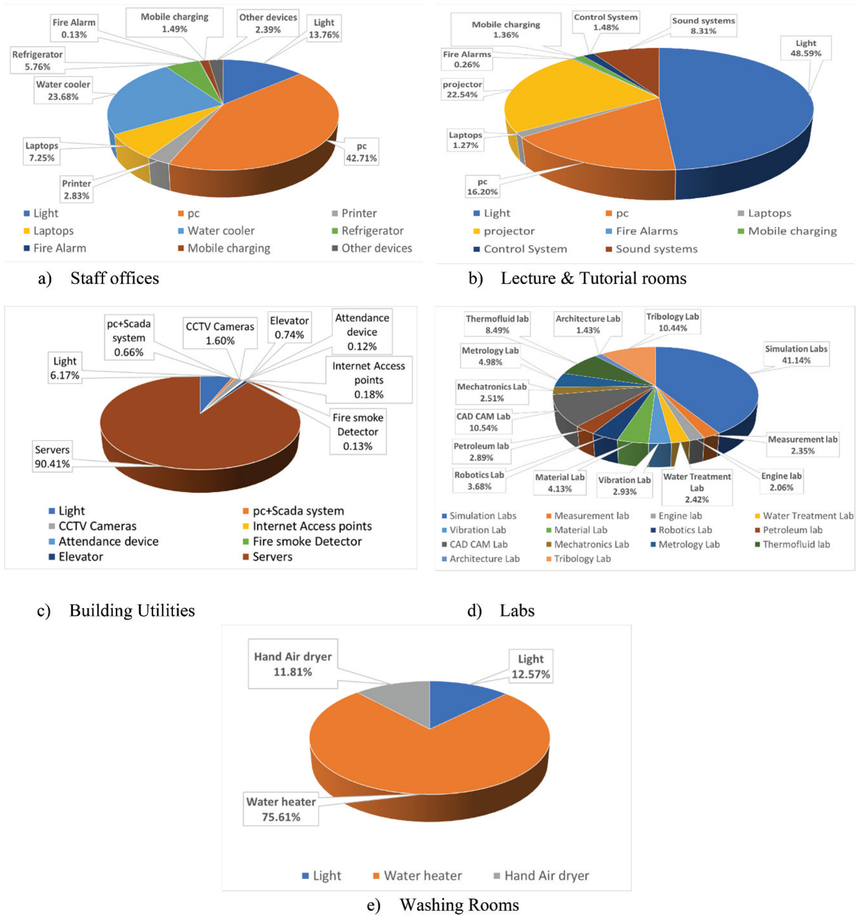
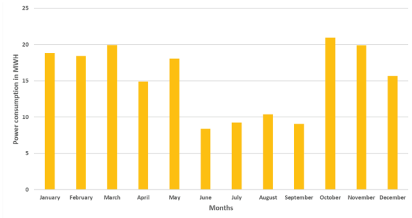


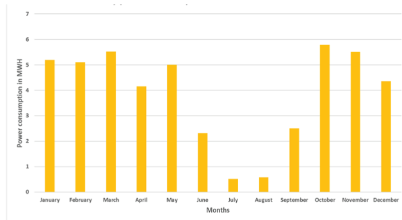
Figure 5. Power consumption percentage in different spaces.

shown in Figure 6f. The total power illustrated in Figure 6g has the highest consumption value in October of 544.38 MWhel, other peaks are in June, July, August and September mainly due to the usage of AC and the variation between them because of the vacations. On the other hand, the lowest monthly consumption occurred in April with a value of 160.58 MWhel

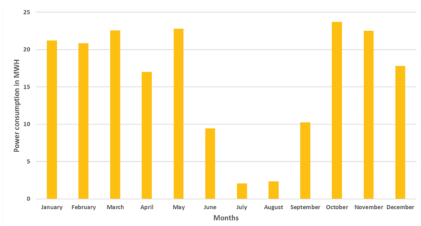
The results of the analysis show that the average EUI in the engineering building is 330 kWh/m^2; at first glance this value may seem very high compared to other reported similar case studies (217.1 kWh/m^2 by Hamida et al. [35] and (28.99–119.5) kWh/m^2 by Chihib et al., the highest EUI of 119.5 kWh/m^2 was observed in the Research buildings [36]). Moreover, the results are also slightly higher than those reported by Khoshbakht et al. [10] on university campus buildings in Australia for different building classifications (academic, administration, library, research, teaching,



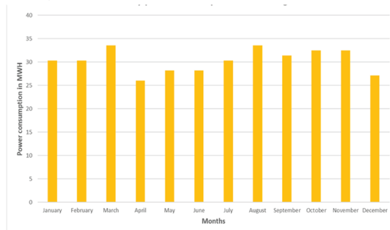
a) Staff Offices



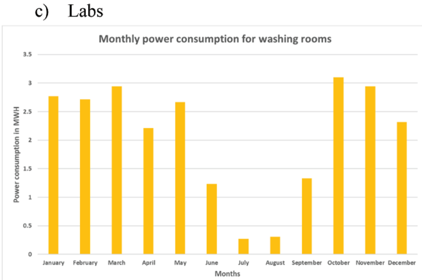
b) Lecture & Tutorial Rooms



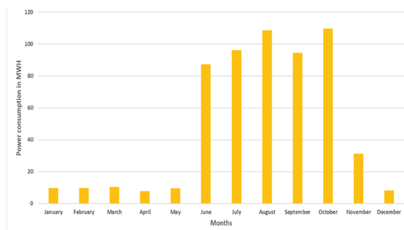
c) Labs



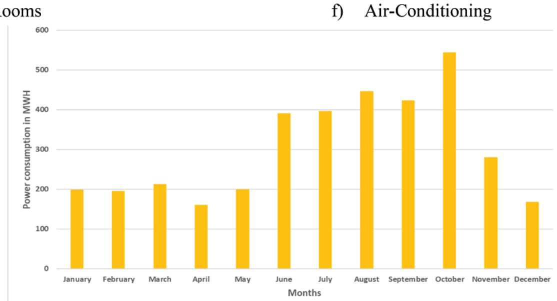
d) Building Utilities



e) Washing Rooms



f) Air-Conditioning



g) Total Monthly power consumption

Figure 6. Monthly power consumption for different spaces.

etc.) which showed that the highest EUI was in the research buildings (379 kWh/m^2) followed by teaching buildings (161 kWh/m^2), library (148 kWh/m^2), mixed activity buildings (141 kWh/m^2), administration (135 kWh/m^2) and academic offices (121 kWh/m^2). However, values of 800 kWh/m^2, 338 kWh/m^2, 404.7 kWh/m^2 and 270 kWh/m^2 are reported for lab spaces, school services (classrooms, Lecture halls & Offices, respectively) in a case study in Canada [37] by Li & Chen and 490 kWh/m^2 (on average varying between minimum value of 250 kWh/m^2and maximum of 800kWh/m^2) for a case study in USA [3] and (450–600) kWh/m^2 for a comparative case study in different universities [3]. These comparisons reflect that EUI varies according to the discipline taught in the building; for instance, science building has higher EUI compared to others, also the least EUI is recorded for public services such as mechanical/electrical rooms and storage areas). The comparison also shows that the EUI is affected by the geographic location, type and nature of the activities in the high education building and the building construction date, irrelevant of the location.

Heat gain data analysis

The conduction through building envelope, including exterior walls, roof, and fenestrations, is shown in Figure 7. In Summer, the peak heat gain periods are in July and August, due to the extreme hot temperatures, while in Winter, the peak periods are January and February, consequently the power consumption of the air conditioning system or heat pump is noticeably increasing in these periods to achieve the desired comfort zone in the building. In April, the average day temperature is equal to the design thermal comfort temperature (21°C), thus the change in temperature is zero and consequently conduction through building envelope equals zero.

In Figures 8 and 9 below, the heat gains from people and lighting are nearly the same throughout the teaching period from October to May, while from June to September, heat gain is reduced because of students' absence. In order to maintain thermal comfort and prevent excessive dryness of the air in the building, the air conditioning system must satisfy both sensible and latent heat gains from people.

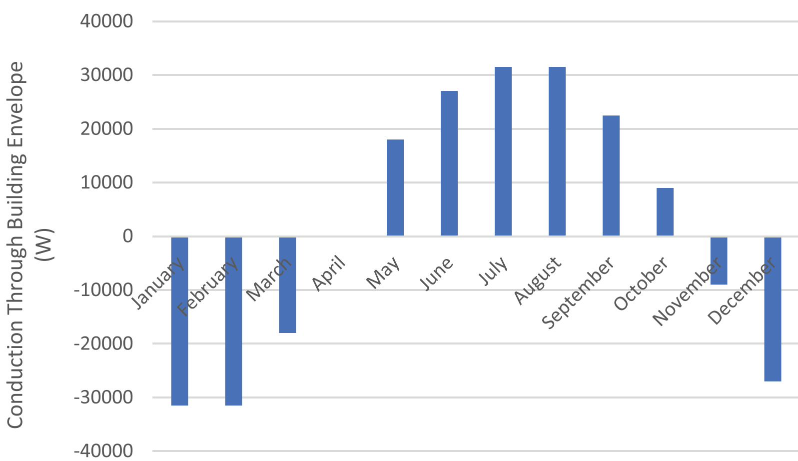


Figure 7. Conduction through building envelope.

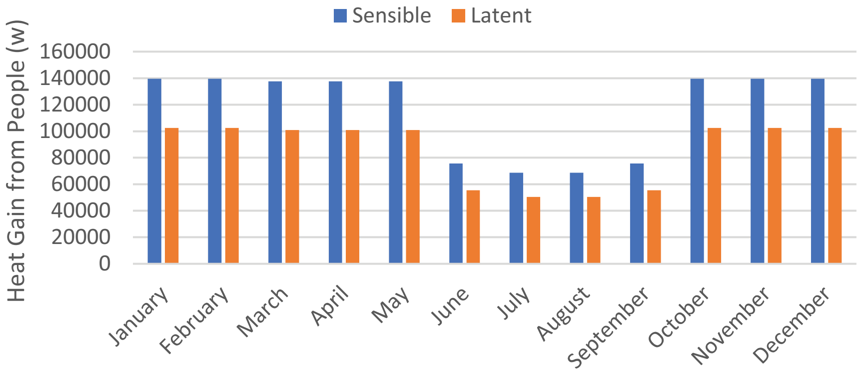


Figure 8. Heat gain from people.

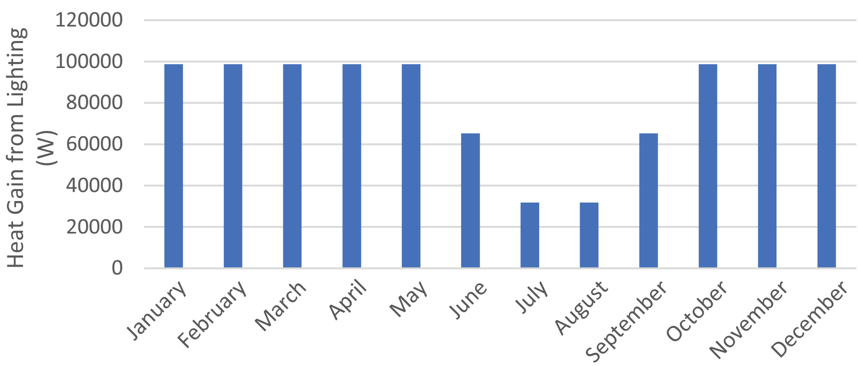


Figure 9. Heat gain from lighting.

The total heat gain distribution throughout the year is shown in Figure 10, and the peak periods are May and October because of the high outside temperatures and the high number of students and staff in the building. The highest electricity bills are expected to be in the peak periods, therefore efficient solutions must be suggested to reduce the heat gain, considering the peak values.

Conclusions

Despite the special nature and diversified increased energy need in university campuses, not enough studies appear to be assisting in providing procedures for actual implementation of steps facilitating collecting the data on energy usage of university buildings. Therefore, the main objective of this study is to provide simple guidelines for collecting energy performance data and

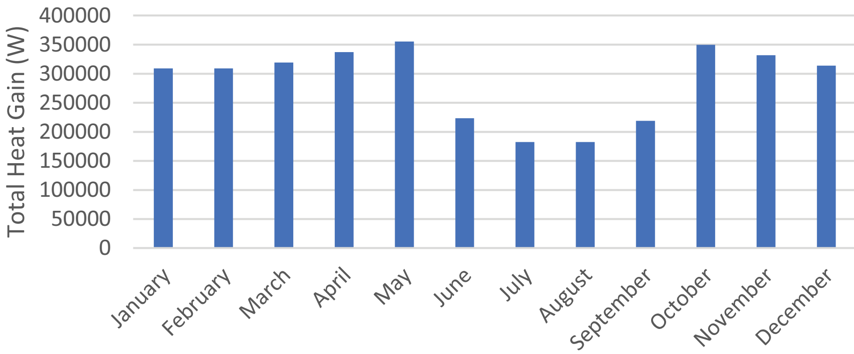


Figure 10. Total heat gain.

presenting it in an appropriate form for data analysis. Those guidelines are developed based on a case study of a building at an Egyptian university. The study aims at identifying the needed analysis parameters and the type of data needed to quantify those parameters in line with recommended codes and/or standards. The main outputs of the current work can be highlighted in the following points:

- The offered database will be the first seed of online database for Energy in Egyptian Building benchmarking.
- Organized guidelines/steps in collecting data should be followed in all educational buildings in Egypt.
- The simulation labs consume more energy 36.79% than other labs; this is because most PCs are left working for a long time.
- The highest power consumption is in October of 544.38 MWh, other peaks are in June, July, August, and September due to the usage of AC and the variation between these months due to the vacations.
- July and August are the peak heat gain periods, due to the extreme hot temperatures in Egypt, while January and February are the peak periods in Winter, and the power consumption of the air conditioning system or heat pump is noticeably increasing in these periods to achieve the desired comfort zone in the building.
- In April, the average day temperature is equal to the design thermal comfort temperature, and consequently conduction through building envelope equals zero.
- The Energy Use Index (EUI) parameter is the key indicator of energy building consumption which should be compared with the international energy levels. Compared to international reported values in case studies, the EUI of Building A in the British university in Egypt is about 330 kWh/m^2, lying

between the minimum 28.99 kWh/m^2 and maximum 800 kWh/m^2 reported in literature for similar university campus buildings.

- Educational building staff and students should practice energy saving operation.

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References

1. Alshuwaikhat HM, Abubakar I. An integrated approach to achieving campus sustainability: assessment of the current campus environmental management practices. J Clean Prod. 2008;16(16):1777–1785. doi:10.1016/j.jclepro.2007.12.002
2. Heidarinejad M, Cedeno-Laurent JC, Wentz JR, et al. Actual building energy use patterns and their implications for predictive modeling. Energy Convers Manag. 2017;144:164–180. doi: 10.1016/j.enconman.2017.04.003
3. Ma Y, Lu M, Weng J. Energy consumption status and characteristics analysis of university campus buildings. Proceedings Of The 5th International Conference On Civil Engineering And Transportation, Korea. 2015;1. doi:10.2991/iccet-15.2015.232
4. Zhou X, Yan J, Zhu J, et al. Survey of energy consumption and energy conservation measures for colleges and universities in Guangdong province. Energy Build. 2013;66:112–118. doi:10.1016/j.enbuild.2013.07.055
5. Escobedo A, Briceno S, Juárez H, et al. Energy consumption and GHG emission scenarios of a university campus in Mexico. Energy Sustain Dev. 2014;18:49–57. doi:10.1016/j.esd.2013.10.005
6. Chung MH, Rhee EK. Potential opportunities for energy conservation in existing buildings on university campus: a field survey in Korea. Energy Build. 2014;78:176–182. doi:10.1016/j.enbuild.2014.04.018
7. Guan J, Nord N, Chen S. Energy planning of university campus building complex: energy usage and coincidental analysis of individual buildings with a case study. Energy Build. 2016;124:99–111. doi:10.1016/j.enbuild.2016.04.051
8. Sait HH. Auditing and analysis of energy consumption of an educational building in hot and humid area. Energy Convers Manag. 2013;66:143–152. doi:10.1016/j.enconman.2012.10.005

9. Sekki T, Airaksinen M, Saari A. Measured energy consumption of educational buildings in a Finnish city. Energy Build. 2015;87:105–115. doi:10.1016/j.enbuild.2014.11.032
10. Khoshbakht M, Gou Z, Dupre K. Energy use characteristics and benchmarking for higher education buildings. Energy Build. 2018;164:61–76. doi:10.1016/j.enbuild.2018.01.001
11. Medrano M, Martí JM, Rincón L, et al. Assessing the nearly zero-energy building gap in university campuses with a feature extraction methodology applied to a case study in Spain. Int J Energy Environ Eng. 2018 Sep;9(3):227–247. doi: 10.1007/s40095-018-0264-x
12. Ferrari S, Beccali M, Caputo P, et al. Electricity consumption analysis of tertiary buildings: an empirical approach for two university campuses. J Archit Eng. 2020 Jun;26(2):05020005. doi: 10.1061/(ASCE)AE.1943-5568.0000415
13. Oh J, Hong T, Kim H, et al. Advanced strategies for net-zero energy building: focused on the early phase and usage phase of a Building's life cycle. Sustainability. 2017;9(12):2272. doi: 10.3390/su9122272
14. Yıldız Y, Koçyiğit M. Energy consumption analysis of education buildings: the case study of Balikesir University. Gazi Univ J Sci. 2021;34(3):665–677. doi: 10.35378/gujs.722746
15. Fitriani H, Rifki M, Indriyati C. Citra Indriyati, Aditya Rachmadi, Ahmad Muhtarom (2021). Energy analysis of the educational building in Palembang Indonesia. Civil Eng Arch. 2021;9(3):778–788. doi: 10.13189/cea.2021.090319
16. ANSI/ASHRAE/IES Standard 90.1: Energy Standard for Buildings Except Low-Rise Residential Buildings. 2022.
17. Janssen R. Towards energy efficient buildings in Europe. London: Europ Alliance Comp Energy Efficiency Build. 2005; 45–50.
18. Torres-Navarro J, Bastida-Molina P, Honrubia-Escribano A and Gómez-Lázaro E. 2022. Analysis of electricity consumption in university buildings and possible improvements due to Spanish financial helps announcement. Study of the state of the art. In: 20th International Conference on Renewable Energies and Power Quality (ICREPQ'22); Jul 27-29; Vigo (Spain).
19. Chun Wang J. Energy consumption in elementary and high schools in Taiwan. J Cleaner Prod. 2019;227:1107–1116. ISSN 0959-6526 10.1016/j.jclepro.2019.04.254
20. Alam M, Raza Devjani M. Analyzing energy consumption patterns of an educational building through data mining. J Buil Eng. 2021;44:103385. doi: 10.1016/j.jobe.2021.103385
21. United Nations Development Programme. Energy efficiency in buildings in Egypt: opportunities, challenges and solutions; 2013 [Accessed 2021 Sept 27]. https://www.undp.org/content/dam/egypt/docs/Energy-Efficiency-in-Buildings-in-Egypt.pdf
22. Egypt: Energy efficiency in public schools. European Bank for Reconstruction and Development (EBRD); 2019 Feb 28 [Accessed Sept 27, 2021]. https://www.ebrd.com/news/2019/egypt-energy-efficiency-in-public-schools.html
23. El Sayed M, Kandil A. Energy performance assessment of a primary school building in Egypt: case study. Int J Sustain Energy. 2018;37(8):767–780.
24. National Program for Energy Efficiency in Buildings (NPEEB). Ministry of housing, utilities, and urban communities; n.d. [Accessed Sept 27, 2021]. https://www.npeeb.gov.eg/

25. Green School Initiative. United Nations Development Programme; n.d [Accessed Sept 27, 2021]. https://www.arabstates.undp.org/content/rbas/en/home/ourwork/environmentandenergy/successstories/green-school-initiative.html
26. Emil F, Diab A. Energy rationalization for an educational building in Egypt: towards a zero energy building. J Buil Eng. 2021 December;44:103247. doi: 10.1016/j.jobe.2021.103247
27. Elshamy AI, Elshazly E, Oladinrin OT, et al. Challenges and opportunities for integrating RE systems in Egyptian building stocks. Energies. 2022;15(23):8988. doi: 10.3390/en15238988
28. International Code Council, Building Officials, Code Administrators International, International Conference of Building Officials, & Southern Building Code Congress International. International energy conservation code. Washington DC: International Code Council; 2000.
29. ANSI/ASHRAE Standard 55R. Thermal environmental conditions for human occupancy. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc.; 2010.
30. ASHRAE, ANSI/ASHRAE Standard 62.1-2010, Ventilation for Acceptable Indoor Air Quality, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, GA; 2010.
31. ASHRAE, Thermal Environmental Conditions for Human Occupancy, in ANSI/ASHRAEStandard 55-20R10; 2010.
32. ANSI/ASHRAE/IES Standard 90.2: Energy Efficient Design for low-Rise Residential Buildings; 2019.
33. Energy Efficiency Indicators: Fundamentals on Statistics, International Energy Agency, OECD/IEA; 2014.
34. Cooling and Heating Load Estimation A Trane Air Conditioning Clinic; 2000.
35. Hamida MB, Ahmed W, Asif M, et al. Techno-economic assessment of energy retrofitting educational buildings: a case study in Saudi Arabia. Sustainability. 2021;13(1):179. doi: 10.3390/su13010179
36. Chihib M; Salmerón-Manzano E; Manzano-Agugliaro F. Benchmarking energy use at University of Almeria (Spain). Sustainability. 2020. doi: 10.3390/su12041336, 12, 1336.
37. Li S, Chen Y. Internal benchmarking of higher education buildings using the floor-area percentages of different space usages. Energy Build. 2020;110574:110574. doi: 10.1016/j.enbuild.2020.110574