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Higher Educational Building Summer Energy Audit: A Case Study in Electrical Engineering Department at Assiut University in Egypt

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***Abstract*—** Higher education buildings represent a category of buildings that consumes a significant amount of energy; thus, contributing remarkably to the total energy consumption of any country. In this paper, an energy audit was conducted in a higher education building for summer load taking the building of the electrical engineering department in Assiut University as a case study. The building is of a total floor area of around 3604.5 m^2, and located in a hot summer climate of the Egyptian city of Assiut. A detailed description of the building, its directions and the places inside the building are introduced, and a full weather analysis of the region surrounding the building is conducted. Moreover, human activities inside the building are discussed, and an analysis of energy consumption and load classification of the building are introduced. The three main pillars of this study are scheduling the rated nominal power of all appliances in the building, measuring the actual energy consumption of the building, and correlating between them through two important drivers, i.e., weather and human activities. The analysis shows a strong effect of human activities in controlling energy consumption in the building so the consumption increases on school days and decays on holidays.

***Keywords*—** Energy analysis; Energy audit; Human activities; Educational building; Weather analysis; Load classification.

1. INTRODUCTION

The energy audit is a mandatory process for buildings that intend to reduce energy consumption and increase the efficiency of energy use in the building.

In previous papers, a lot of building types are studied. Some studied hospitals and others studied hotels. Other types like administration buildings, educational buildings, and residential buildings are all studied in different countries around the whole world [1-4].

Studies of [4-6] were conducted under hot weather as our study took cooling demand as a driver on consumption. On the other hand, other studies were conducted under cold weather taking heating demand as a driver on the consumption [7-12]. In [9, 11, 12], researchers concerned more with occupancy as a driver of consumption. PV system was involved in some studies [7]. In [4], researcher studied the consumption as kWh and kWh/m^2 while researchers in [11] studied it as kWh/student as an indication of the effect of student's category on the consumption in educational buildings. Biomass boiler is introduced in [7] as a proposed solution for increasing the efficiency of energy use in an educational building.

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Among all types of buildings, we found that the type of educational building is the most interesting one and thus, in this paper, we took an educational building as a case study. Our interest in the educational type of the buildings is attributed to that the higher education building is one of the most suitable places to conduct such a study since it is a place where you find a community with environmental knowledge and awareness of the importance of such study [1]. In addition, it is the home of research and technology development which qualify it to introduce itself as leading in sustainability challenges [1]. But in higher education buildings, there is a knowledge gap between what people know and what they must know about energy use in the building. People are usually concerned with the general performance of energy in the building, but little is known about the reasons (or drivers) of changes in the energy demand and consumption such as population and number of staff members and their variable behavior towards electricity and changes in weather in the surrounding area which changes the thermal load on the building. This knowledge gap represents the weak point which we get rid of in this study by understanding the energy use in the building and by accurately monitoring the energy use, demand, and consumption using measuring devices installed on the main electric panels feeding the building continuously for the whole summer season and measuring all electric quantities in each second. The main objective of this study is to analyze the weather surrounding the building and then analyze the human activities in the building and finally analyze the energy consumption in the building in these summer months indicating the effect of weather and human activities on it.

2. PROPOSED METHODOLOGY

The two main studied factors were the building with its subfactors such as directions, location and activities inside it. Another factor is the weather which remarkably affects consumption as we will discuss later in this paper. Fig. 1 summarizes these factors graphically.

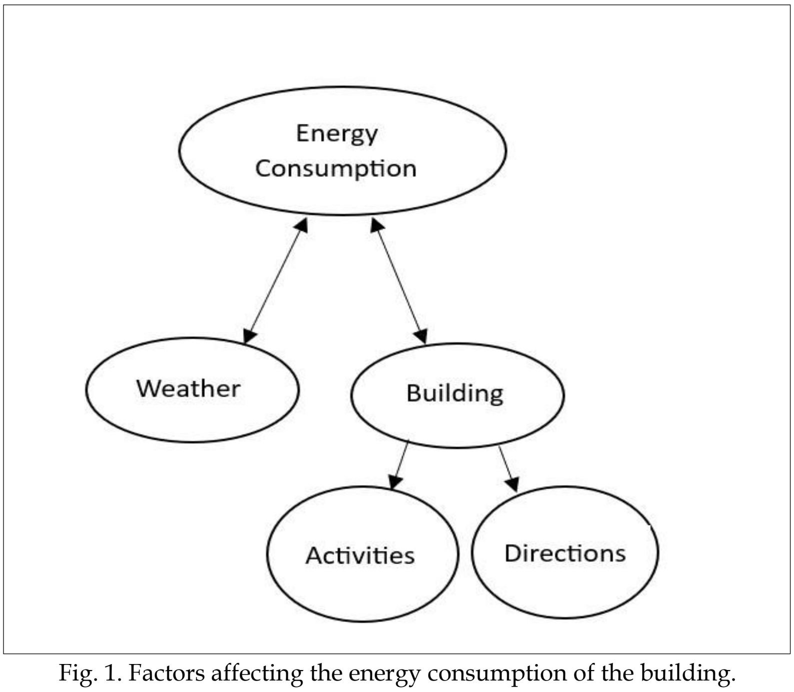

Fig. 1. Factors affecting the energy consumption of the building.

2.1. Building Description

The building considered in this study consists of two buildings attached through a pathway. One of them -which we call the main building- is a 3-story building and the other - called the laboratories building- is a 5-story one. The total floor area is around 3604.5 m^2 lying in Assiut City as shown in Fig. 2. The area of the main building is around 2693.25 m^2 and the area of the laboratories building is around 911.25 m^2. Fig. 3 shows a plan view of the first story in the buildings to visualize the orientation of the buildings and how they are attached.

Fig. 2. Location of the building in Assiut city.

Fig. 3. Plan view of the building's the first floor.

2.2. System Environment Analysis

2.2.1. *Outside Building Summer Weather Analysis*

Assiut City - at which the building lies - is located in the south of Egypt on the east side of the river Nile. It lies at a latitude of 27.05°N and a longitude of 31.02°E where the climate is hot and dry. In summer months (from May to September), the maximum temperatures range between 38 °C and 45 °C and the minimum temperatures range between 14 °C and 21 °C. These high temperatures increase the load on the air conditioners in the building which increases the energy consumption remarkably in summer months due to the increased thermal load as we will discuss in detail in a later section of this paper.

In winter months (from October to April), the maximum temperatures range between 24 °C and 38 °C and the minimum temperatures range between 3 °C and 9 °C. Due to this cold weather, the use of heaters increases in the building but it is still small when compared to AC loads during summer months as we will see later in this paper.

Monthly average temperatures through the year range between 21 °C and 39 °C for high temperatures and between 7 °C and 24 °C for low temperatures as shown in Fig. 4.

There is a large difference between high and low temperatures reaching 10 °C per day and reaching 30 °C per month. From Fig. 4, we found that the average temperature of months from May till September exceeds 36 °C. So, in this study, we studied these five months

[May, June, July, August, and September] as the hot summer months. Fig. 5 shows the high and low and average temperatures for each day in these studied summer months and the differences between day and night temperatures. We notice that the high temperatures varied around 37 °C and reach 43 °C sometimes as a maximum recorded temperature and 28 °C as a minimum recorded temperature. The low temperatures varied around 23 °C and reaches 28 °C sometimes as the maximum temperature and 14 °C as the minimum temperature. There is a large difference between day and night temperatures that varies between 21 °C and 10 °C with 14 °C as the average difference.

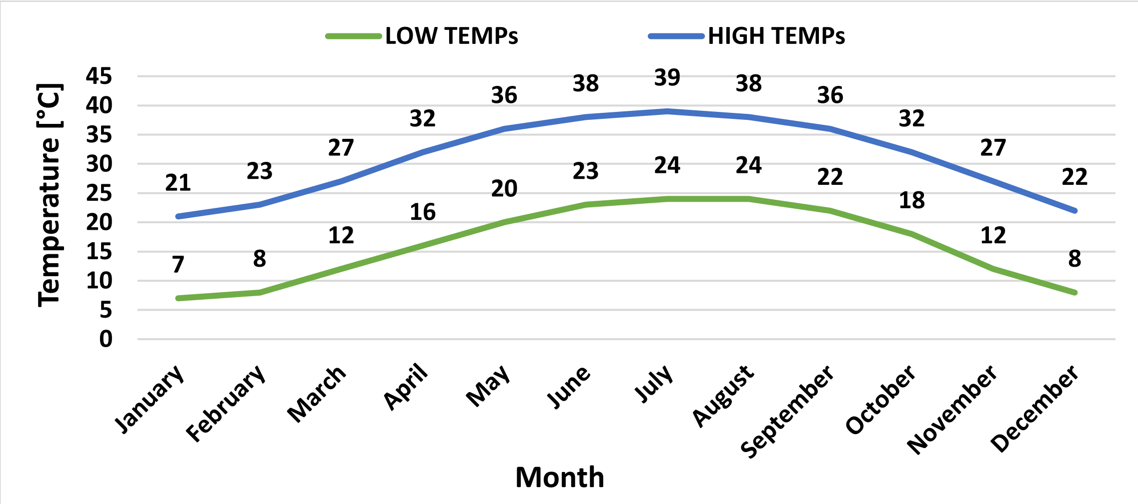

Fig. 4. Monthly average low and high temperatures for the year 2022.

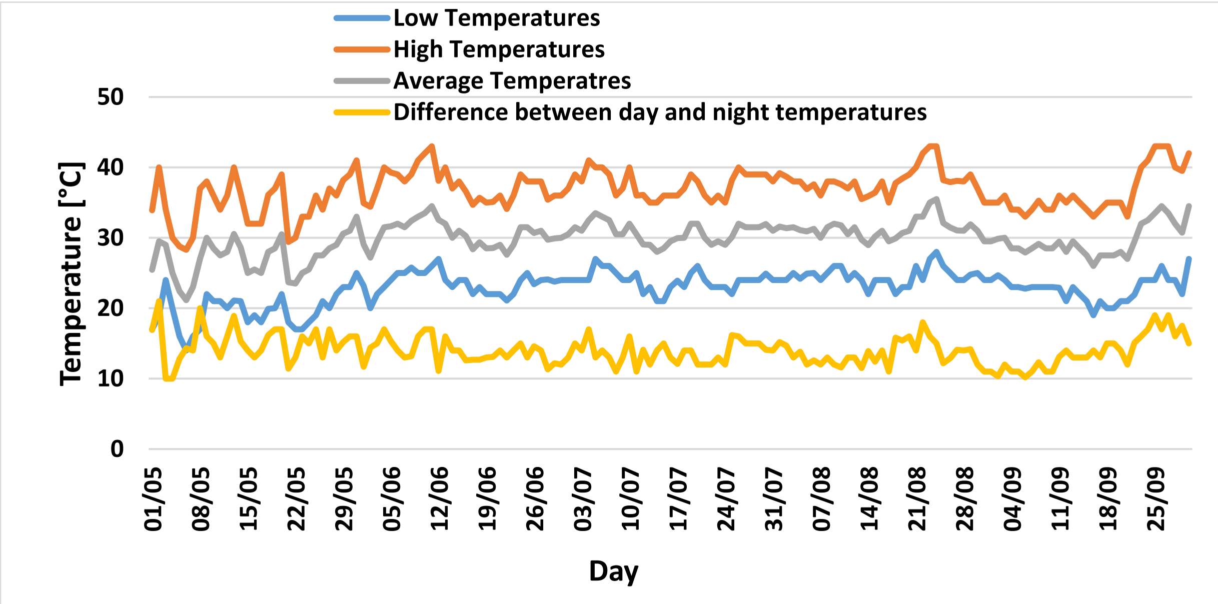

Fig. 5. Daily high, low and average temperatures and the difference between day and night temperatures.

2.3. Human Activities Analysis

The analysis of human activities was conducted through two main steps:

- Work Days
- Schedule

2.3.1. *Work Days*

The human factor in the building is represented in three different categories; students, teaching and research staff, and workers and employees. There are slight differences between days of working for each category. Students, workers, and employees come to the building on the studying days from Sunday to Thursday (all the week except Fridays and Saturdays).

Teaching and research staff come to the building on studying days by default but some of them come to the building every day for research work so this category is considered to exist in the building every day in this study.

2.3.2. *Schedule*

In each working day, the duration of the existence of each category also differs. Workers and employees exist for 6 hours from 8 AM to 2 PM. Students exist for around 11 hours from 8 AM to 7 PM in different densities throughout the day according to the studying schedule. For teaching and research staff, the duration of existence varies from one member to another. But to cover all the periods of existence of each one of them, we took it as 15 hours from 8 AM to 11 PM -in widely different densities through the day- in this study. Periods of the existence of each category are summarized in Figs. 6 and 7.

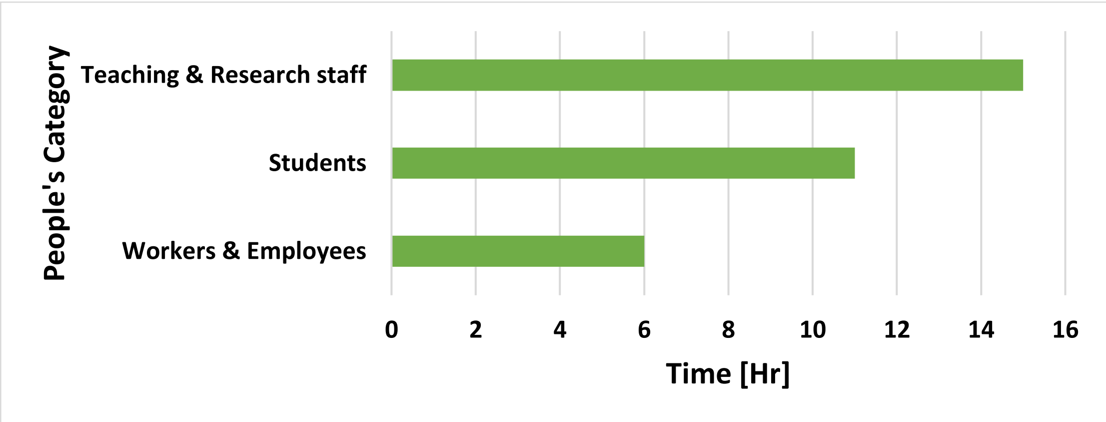

Fig. 6. Periods of people's category existence.

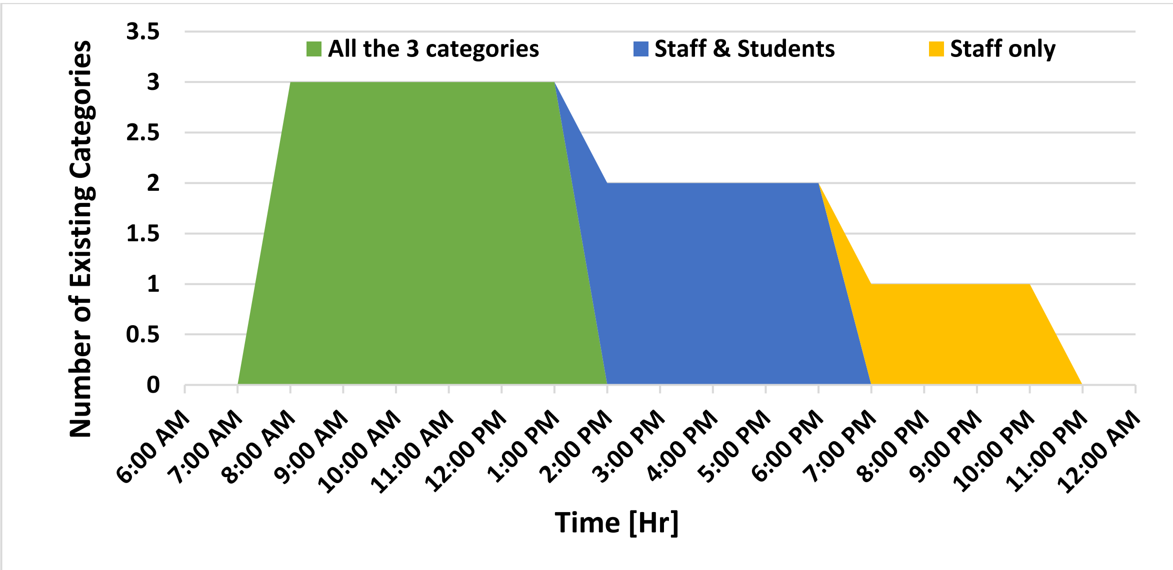

Fig. 7. The existence of people's categories of in the two buildings through a school day.

2.4. Energy Analysis Approach

We used two energy logger devices: one on each main panel at each of the two buildings. these devices were left connected for the whole summer season of the year 2022 and we get the data from them periodically. The devices were recording the readings of all-electric quantities each second. We got a huge amount of data, and it was a must to analyze them carefully to make use of them. The energy analysis process was conducted through two main steps:

- Load Classification
- Energy Consumption Monitoring

3. RESULTS AND DISCUSSION

3.1. Results of Energy Analysis through the Two Buildings

3.1.1. Load Classification

We classified loads in each category of places in each building into 5 main types: Lighting, Fans, Air Conditioning (AC), Machines of Laboratories, and Plug Devices (including kettles, heaters, fridges, computers, printers, and all other various devices).

Figs. 8 and 9 show the distribution of each type of load in each category of place in the two buildings. We notice that the machines of laboratories are concentrated in the main building (specifically on the zero floors) while the laboratories building has no machines in its laboratories. In the laboratories building, AC load is dominant in each place category. The same is applied to the main building unless in labs and service places where the machines and plug-in devices respectively are dominant. The fans represent the smallest load in each of the two buildings. In order to obtain the required data to construct such graph, a very detailed inventory and categorization is conducted of all appliances' nameplates in each room in the building to get the rated power of each, then we classified the appliances' power of each load category in all rooms belonging to the same place category.

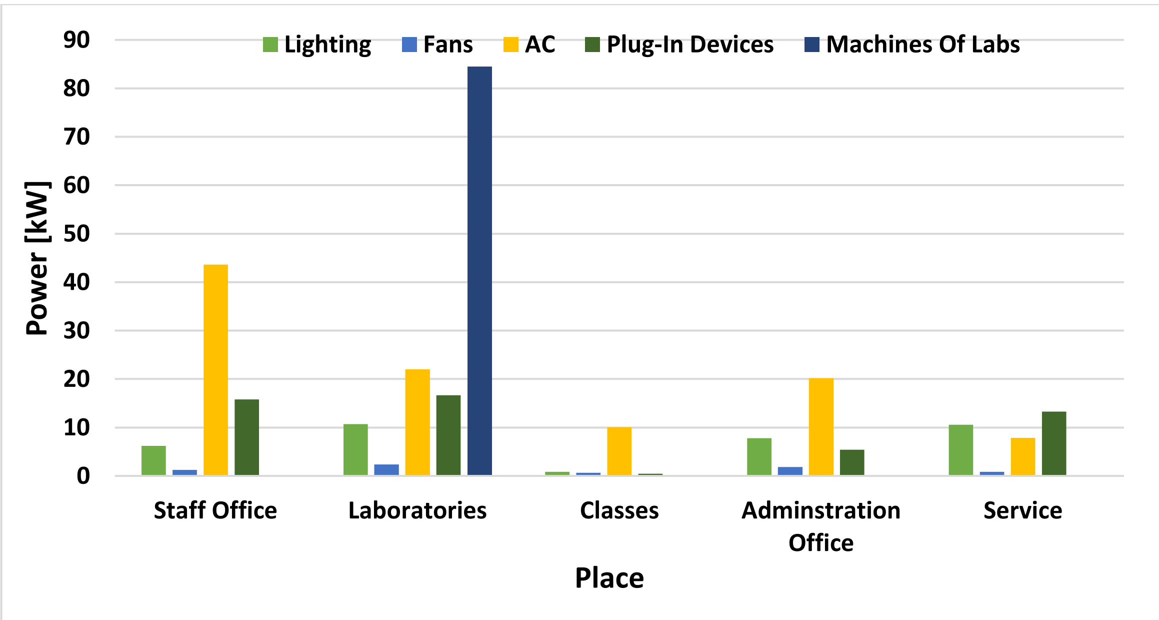

Fig. 8. Classification of loads in the main building.

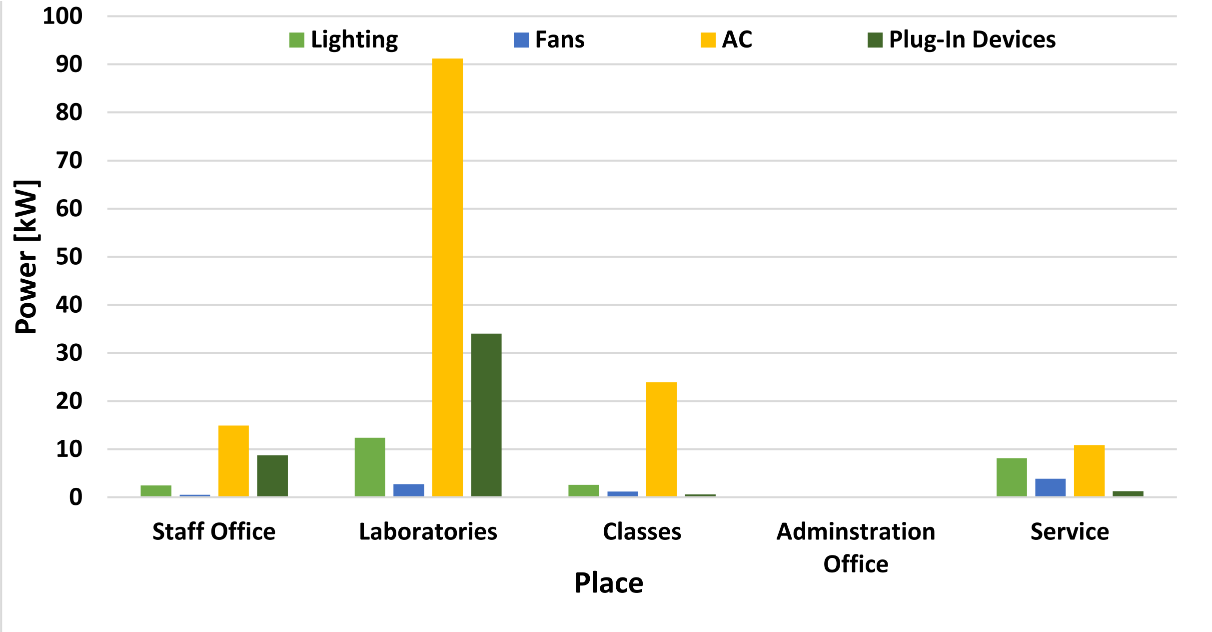

Fig. 9. Classification of loads in the laboratories' building.

Then, we merged the categories of places in each of the two buildings to make a classification of loads in each whole building as one place. Fig. 10 shows the contribution of each type of load to a total load of each building. As expected, we found that the AC load is the dominant type in each building while the fans represent the smallest percent of loads in each building.

Air Conditioners used in the building are all split units operating by freon. The total number of units is 47 units in the main building and 43 units in the laboratories building classified according to their capacities as shown in Table 1.

Table. 1. Available air conditioners in the two buildings.

Capacity [hp]	Number of units	
	Main Building	Laboratories Building
1.5	4	6
2.25	5	1
3	3	13
3.5	1	0
4	8	10
4.5	26	13

As another view for load classification, we detected the contribution of each place category in the total load in each of the two buildings as shown in Fig. 11.

We notice that the laboratories represent the dominant category of places contributing by the largest percentage to the total load of the two buildings and of course, this is attributed to the existence of machines with heavy power in these laboratories. On the other hand, the classes represent the smallest contribution in the main building while service places represent the smallest contribution in the laboratories buildings.

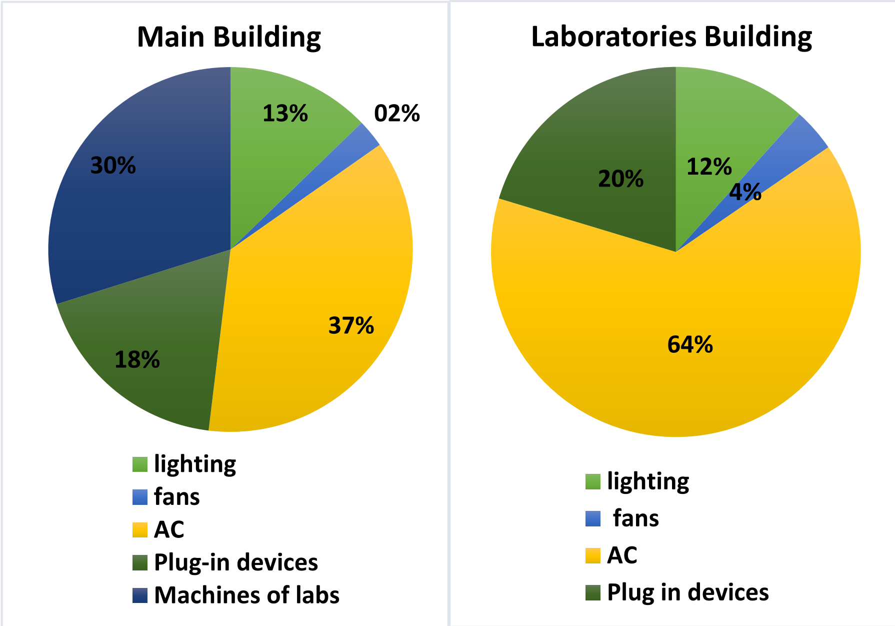

Fig. 10. Percent of load types in the two buildings.

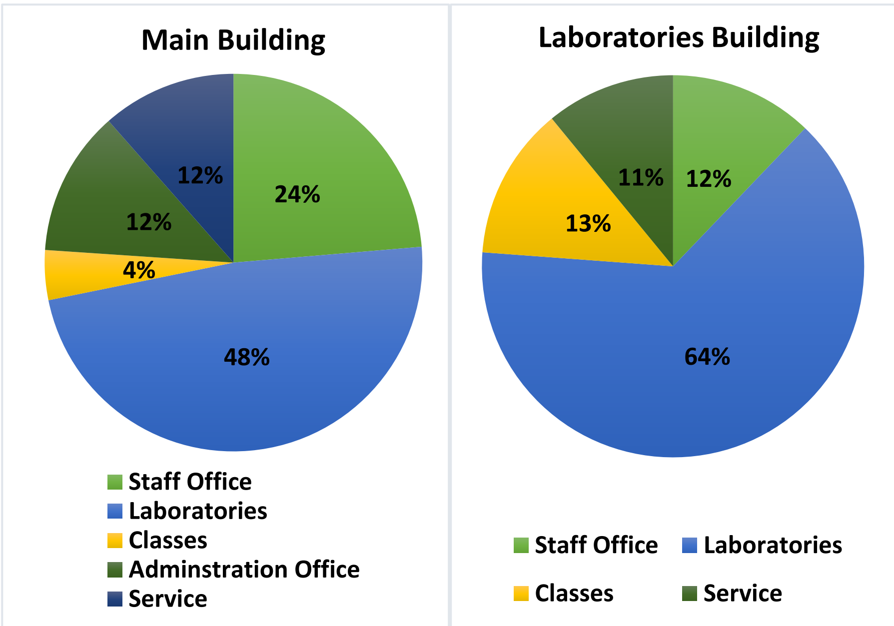

Fig. 11. Contribution of places categories in the total load for the two buildings.

3.1.2. Energy Consumption Monitoring

We monitored the energy consumption hourly, daily, and monthly in an attempt to detect the pattern of consumption. Figs. 12 and 13 show the consumption on each day of the five months in 2022 (from May to September) for the two buildings. From Figs. 12 and 13, we notice that the consumption of the main building is larger than that of the laboratories building as estimated from the load classification.

Also, it is clear that consumption rises during the working days of each week and drops on the weekends (Fridays and Saturdays) and rises again at the start of the next week and so on. This shows the effect of the human factor as a driver of consumption.

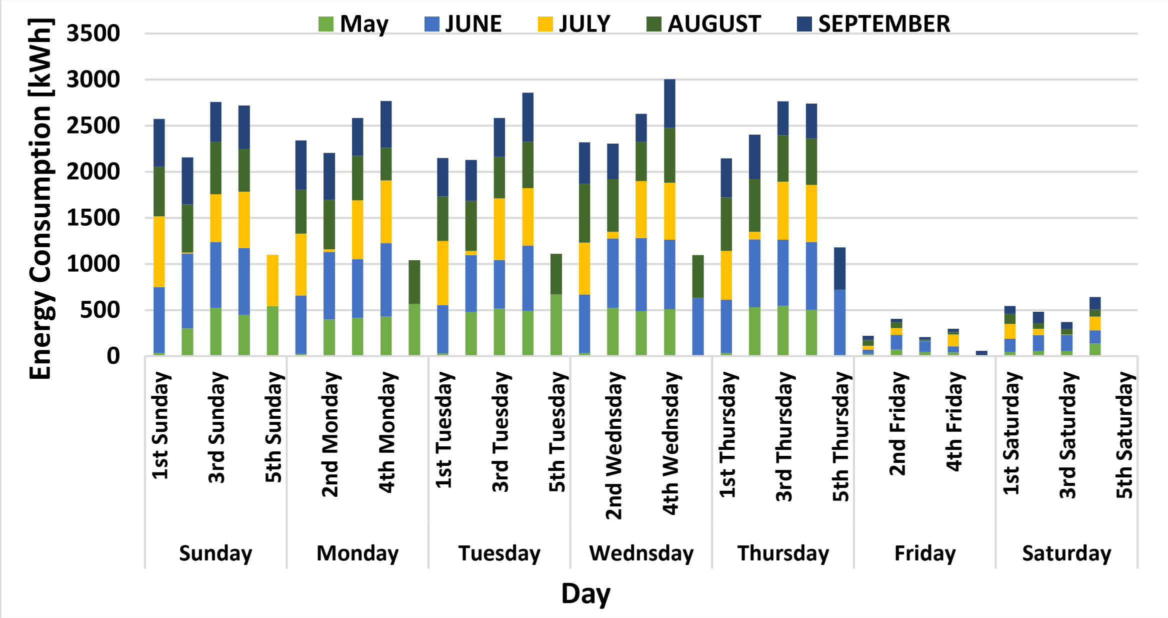

Fig. 12. Daily consumption of the main building for the period of 5 months in 2022.

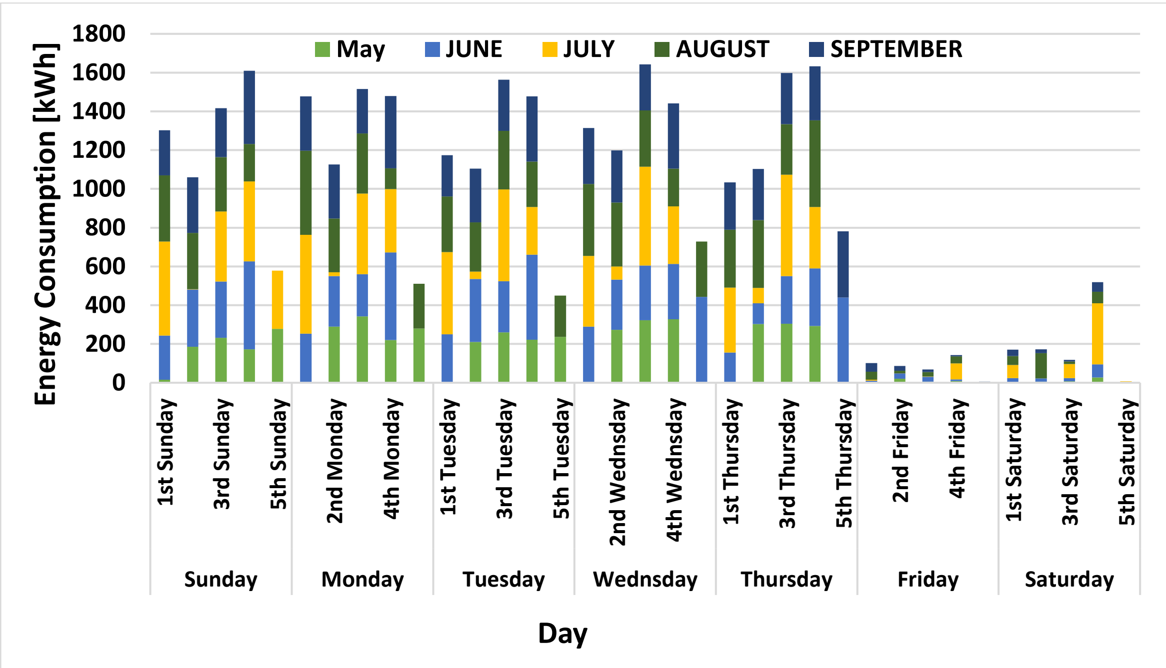

Fig. 13. Daily Consumption of the laboratory building for the period of 5 months in 2022.

For a wider view of consumption, we did a monthly analysis of the data. Fig. 14 shows the monthly consumption for each of the two buildings. In the main building, the maximum monthly consumption occurred in June when it reached 16.24 MWH. In the laboratories building, the maximum consumption occurred in July when it reached 7.1 MWH. So, the peak consumption is in the hottest months of summer as shown in Fig. 14. This indicates the effect of weather on the consumption of the building.

In contrast, for more descriptive analysis, Fig. 15 shows the daily load profile on day 3/8 (as a sample) for each of the two buildings.

From Fig. 15, we notice that the consumption rises gradually starting from 7 or 8 AM reaching its maximum at noon (the peak time) and then goes down gradually till 2 PM and continue decreasing to the bottom. The period 8 AM to 2 PM, has the largest part of the consumption cross the day because this is the period during which all the 3 categories of people occupy the two buildings as we demonstrated in the previous section of this paper by Fig. 7.

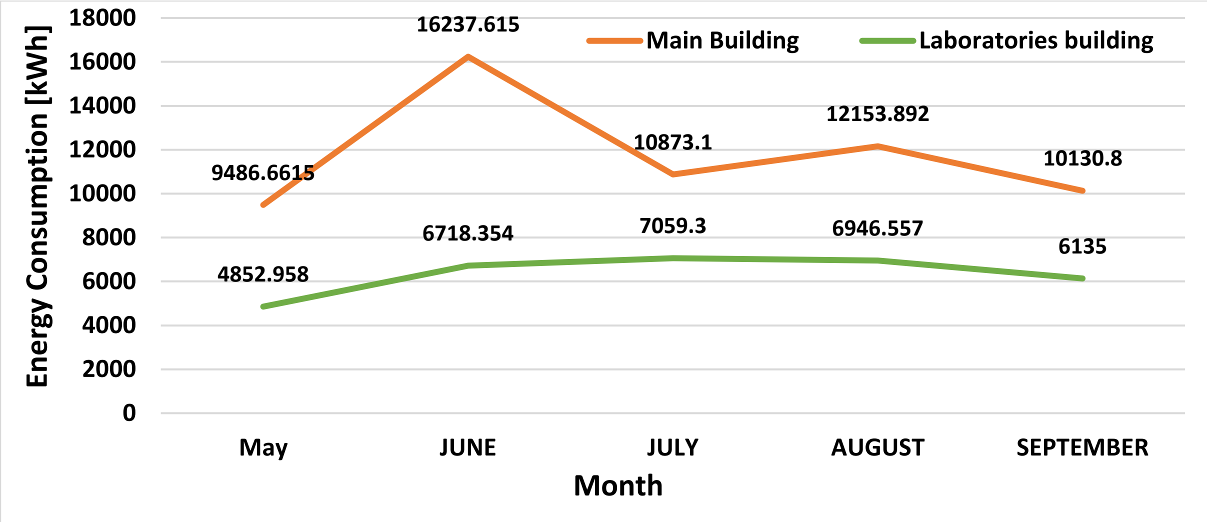

Fig. 14. Monthly consumption of each building for the summer season.

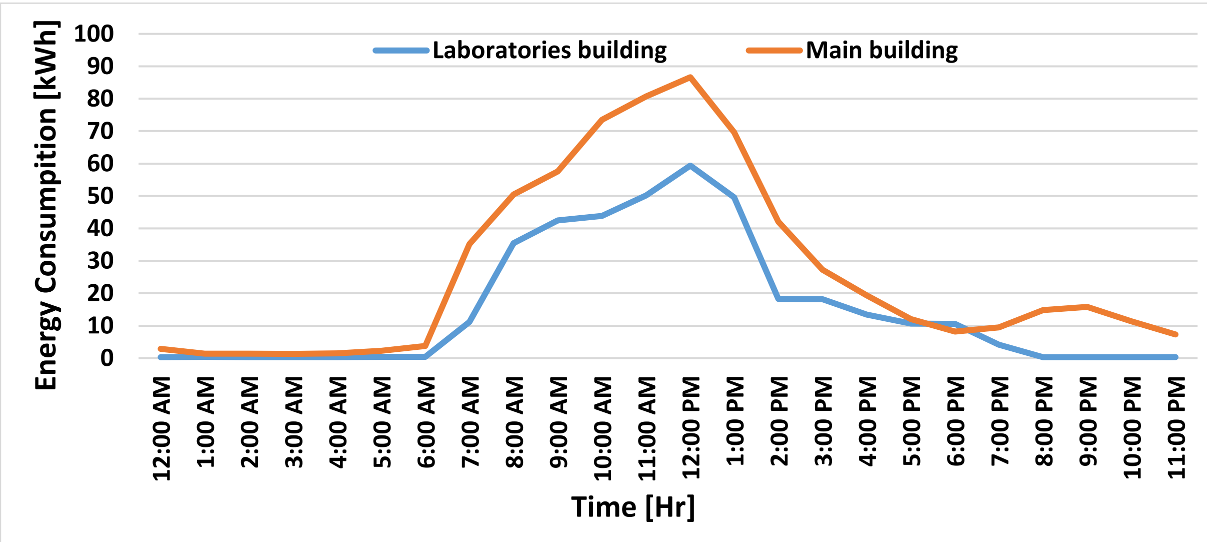

Fig. 15. Load profiles of two buildings on August 3, 2022.

4. CONCLUSIONS AND FUTURE WORK

Based on the performed analysis, we can conclude the following:

- There is a remarkable difference in temperatures of day and night which can be effectively used in day and night ventilation.
- This change in weather is reflected in the energy consumption so the months with the highest temperatures recorded the highest consumption.
- Human activities contribute significantly to the energy consumption of the building.
- Energy consumption increases with the existence of students (during studying days) as the most effective driver of consumption.

- Based on the findings of this investigation, some recommendations can be suggested to reduce the energy consumption in the building like:
  - Installing shading on the southern side of the building to reduce the thermal loading on air conditioners.
  - Installing thin films on the windows to reduce the heat transfer into the rooms of the building to reduce loading on the air conditioners.
  - Implementing a day and night ventilation system in order to reduce the loading on air conditioners.
  - Implementing daylight harvesting system to reduce loading on lamps in the building, and making use of daylight which is healthier, free of charges and available for about 12 hours [13].
  - Installing a Photovoltaic system on the building surface as a source of renewable energy [14].
- One limitation of this study was the unavailability of a counting system for counting persons existing inside the building during each hour for more detailed correlation between human activities and energy consumption; but, this will be provided in the future work.
- For future research, we intend to count persons entering and exiting the building to obtain the number of persons inside the building on each hour using a visual counting system. This can be correlated with the consumption in these hours to detect the effect of human activities on consumption more precisely and to study the $kWh/m^2/person$ criterion. Also, the recommendations above will be implemented in addition to performing optimization for the schedule of lectures to improve the efficiency of energy use in the building, hoping to reach a nearly zero-energy building.

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