Towards a Sustainable Zagazig University Campus

DISCLAIMER

All software tools used in the current work are licensed and used within the legal boundaries of the license agreement.

Executive Summary

The following report represents a snapshot of the work done in the project "**Towards a Sustainable Zagazig University Campus**" at Zagazig University, Egypt. The project aims at optimizing the energy supply system to ensure a carbon neutral campus with minimum dependence on the grid and with a sustainable source of electricity through a solar PV system. To optimize the system efficiency and to reduce the capital investment, campus loads are optimized and minimized through a comprehensive auditing process to apply all possible energy efficiency measures (EEMs). This auditing process is required since it's not logic or economic to feed an inefficient load from a costly Solar PV system. The solar PV system will then be designed to cover the remaining campus loads in an efficient way.

Its worthy to mention that the current work has started as a B.Sc. Graduation Project for 4^{th} year senior students, and then evolved to be the University Goal for the Sustainable Campus. So, its not strange to know that most of the tasks were performed by senior mechanical engineering students with minimum directions from the faculty staff and assistants. In addition, there is a 105 kWp grid-connected solar PV system designed, commissioned, installed, and operated by the same work group at the faculty of engineering a year before the start of this work. This small system is the nucleus for the big system that will feed the whole campus, and the acquired knowledge and experience was the prime mover for the current project. In Appendix A, a full monitoring report on the performance of the 105 kWp system will be introduced along with the acquired lessons and experiences gained throughout the year-long service of the system. This acquired experience will ensure the sustainability and operability of the whole campus PV system.

The report is subdivided into **Four sections** to reflect the four basic tasks performed during the work.

Section 1 presents background information about the campus, floor areas, electric loads measurements, and current electricity consumption and Tariff. The investigation of the Single Line Diagram and the analysis of the Electricity Bills for the ZU Main Campus showed that the total electricity bill for the year 2021 was

11,00000 EGP. The applied tariff is **two-part** with 1.15 LE/kWh for medium-voltage energy consumption and 60 LE/kW for peak load. There is a **750,883 EGP** Power Factor penalty (for PF ≈ 0.78 < 0.92). Initial inspection showed that changing the tariff from the existing two-part tariff to TOU tariff will provide an annual saving of 402,860 EGP which equals 3.8% saving from annual bill for the energy consumption. If the PF is improved, in addition, the total bill reduction can reach 1,153,743 EGP**.** Measurements of the Campus Daily Load Curve showed that the campus peak load occurs around **noon** which is perfect for the design of the solar PV as it matches the profile of the solar PV generation curve. Accordingly, the following sections with investigate the potential of energy savings due to the reduction of the campus peak load and energy consumption, improving the power factor, and installing the solar PV system to cover the remaining needs of the campus.

Section 2 presents Energy Efficiency Potential in The Campus Buildings. As mentioned above, its necessary to optimize the campus's energy system efficiency to reduce the capital investment of the installed PV system. Campus loads are optimized through a comprehensive auditing process. A sample of six buildings' results is introduced in this section, and the results are projected to the remaining buildings. Applying all possible energy efficiency measures (EEMs) to the campus buildings will result in around **30 %** savings in annual energy consumption (around **2.24 TWh**) with a Capital Investment of 9,232,421 EGP and Levelized cost of Electricity of 0.52 LE/kWh. This LCOE is remarkably lower than any other energy cost (Grid, PV, ..etc). This encourages all possible investment in this direction to fully benefit of the energy efficiency opportunities. The remaining campus energy needs of around of **5.35 TWh** will be covered by the solar PV system as it follows in the LCOE as will be described in Section 3.

Section 3 presents the Solar PV Supply System to Zagazig University Campus. The design and simulation is done using a set of licensed professional software packages. The system design starts with site assessment using Google Earth and AutoCAD. This helps in categorizing the campus into different layers for estimation of available roof areas for the PV system installation. The 3D projection of all buildings is done using Sketch-up with the assistance of height measurements of each building done by the group buildings. Height measurements helped the crew to identify the sloped surfaces and it will be essential in shading calculations. To effectively lower the shading losses results from roof shadowing, the shading analysis is performed using **CURICSUN** shadow simulation tool. This tool gives the net roof area results in minimum shadow over the panel. Continuing the design using this net roof area, a solar PV system with an installed Capacity of 3,302 kWp that has an annual yield of around 5.35 TWh. This is supplying the campus with all what it needs with a Capital Investment of 42,900,000 EGP with a LCOE of 0.83/0.66 LE/kWh with/without the merging cost.

Section 4 introduces a **Projection** for the Optimum Supply System of Zagazig University campus along with the financial and feasibility study performed for the EEMs and PV system. The predicted optimum cost effective supply mix will be around 30 % from EEMs and 70% from the PV system. This mix ensures the lowest investment PV system cost, the minimum system operating cost, and the best economic feasibility. Total investment of (52,132,420 EGP) is required for both energy efficiency (9,232,421 EGP) and PV installation system (42,900,000 EGP). The total monetary savings from the project will be 11, 045, 109 EGP coming from applying the EEMs (2,570,771 EGP), installing the PV system (6,151,630 EGP), the peak load charges reduction (1,436,256 EGP), and avoiding the power factor penalty (886, 452 EGP). The project is economically feasible and attractive based on a payback period of **6 years** and the **Internal Rate of Return (IRR)** of **21.3 %** even with including the merging cost of 0.257 EGP/kWh. Without including the merging cost, the project becomes more attractive. The payback period decreases to **5.2 years** and the **IRR increases to 23.6 % (**increases by 10.7 %) for same financial parameters. This ensures a sustainable carbon neutral campus with an annual **CO_2 saving** of **3,510 ton**.

Appendix A: Performance monitoring of the pilot 105 kW installed PV system run and sustained by Faculty of engineering, ZU. Zagazig university managed to have this pioneer demonstration project as the first sustainable university in Egypt and it inspired the working team to extend the vision to the whole campus. This small 105 kW system will be the nucleus for the whole sustainable campus. In this appendix, a detailed analysis of the system design, planning, feasibility, and performance monitoring is provided. More important, it provides the learnt lessons from running and maintaining the 105 kW system. This will help maintaining and sustaining the future whole campus system.

University Vision to keep and Maintain the System is developed based on the previous experience of running the pilot 105 kW system. Actually, it's a learning process that developed over the year of servicing and monitoring the system. Since the major problem of the 105 kW system was the need for frequent and continuous cleaning of the system, students can be involved in this process within their free time with supervision from the university's energy efficiency unit. It is planned to offer a paid student working hours to those interested students. In addition to the financial benefit that they will get from doing that, student participation will have the benefit of raising the awareness of a big class of the campus community. This will extend the university's sustainability vision to the outside community as well. Finally, the university has an ambitious plan to apply for the ISO 50001 for energy management system. This will confirm the university's commitment to keep the environment, maintain a sustainable campus, and to continue in the energy utilization improvement plan.

The External benefits of installing the campus PV system is exceeding achieving the campus carbon neutrality and sustainability. The University has an ambitious plan of exploiting the system to its full extent. The experience obtained in designing and running the system will enable the university to run as an excellence center providing expertise and knowledge in solar PV design and installation. This really matches the governmental and global interests of sustainability and energy efficiency. In addition, it is planned that the energy efficiency unit at ZU will provide consultancy services for installing similar systems on governmental and private organizations along with monitoring and performance evaluation. **Society and community engagement** is not overlooked in ZU's vision. It is intended to provide free educational and instructional workshops to raise the awareness of the importance of energy efficiency and sustainability. Capacity building of knowledgeable engineers and operators of similar PV systems is one of the goals of the energy efficiency unit at ZU. Furthermore, high school students' visits and activities is planned as well. Its worthy to mention that faculty of engineering has an extended experience in dealing with STEM students and participating in their activities. This will broaden the exposure of pre-university students to such amazing experience of learning about PV systems in real life in addition to monitoring the performance of an already exiting system. Overall, the campus PV system will be the focus of many social engagement activities.

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Section 4: Optimum Supply System of ZU campus

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Section 1: Background Information about Zagazig University (ZU) Main Campus

Zagazig University Main Campus

- Around **160,000 students** in 13 colleges (Faculties), see **Figure 1.**
- Graduate Studies, Research and Cultural Relations Sectors
- Education and student affairs sector, youth welfare and university city.
- Environmental Service and Community Development sector.
- University hospital sector.

Off Campus Faculties

- 3 Faculties & 3 Institutes
- Other facilities (Stadium, Conference Hall Building, Covered hall, etc.)

Figure 1 Zagazig University Main Campus

Statistics of the Main Campus

Main campus areas are summarized in **Table 1** below. The campus has 62 buildings with net flat roof area of 91,298 m2. Of this area, a certain part will be used for installing the PV system panels. This comes after analyzing the shadows and decide the net effective usable area.

Table 1 Statistics of The main Campus

Total Campus Area	340,000 m^2
Number of Buildings in Campus	62
Percentage of Building Area	29.67%
Buildings with Flat Roof	91,298 m^2
Buildings with Inclined Roofs	9,603 m^2
Steel Buildings	13,687 m^2
Green Areas	35,539 m^2
Playground Areas	8,839 m^2
Internal Roads	50,695 m^2

Electrical Supply System Applied Tariff

From the Single Line Diagram and Electricity Bill (Feb., 2022) for the ZU Main Campus shown in **Figure 2** below, the following remarks can be made on the campus situation:

- The campus has four feeders coming from two different sources to ensure supply reliability.
- It has six electric meters that supply 29 transformers. Each transformer feeds a group of campus buildings.

❑ **The Applied tariff** is the (two-part tariff):

- for medium voltage (1.15 LE/kWh).
- For peak load (60 LE/kW)
- Power Factor penalty (for PF < 0.92)

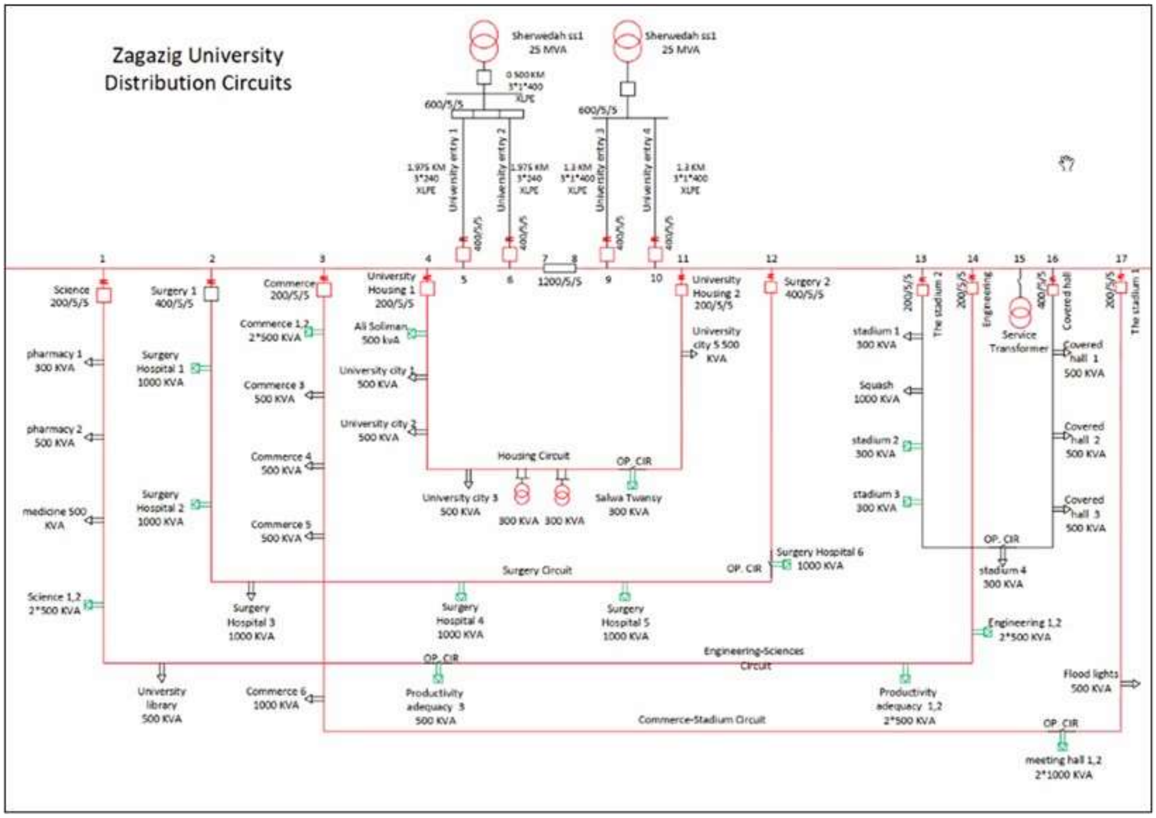
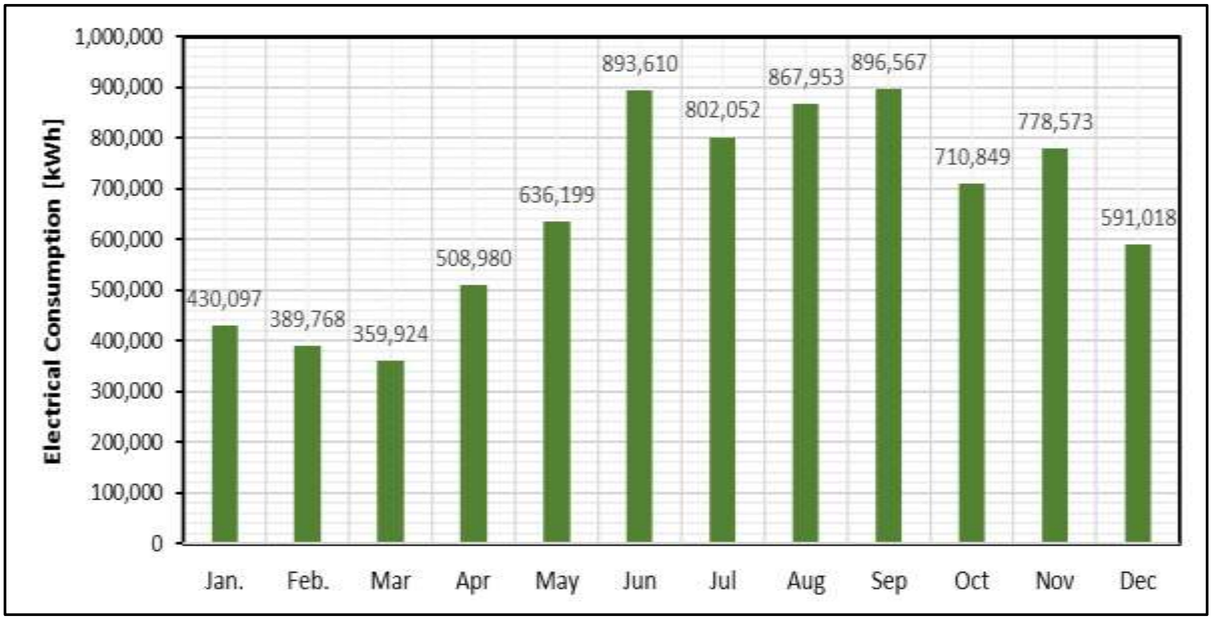


Figure 2 Single Line Diagram and Electricity Bill (Feb., 2022) for the ZU Main Campus

Analysis of Electricity Bills for the year 2021

Figure 3 shows Electric Energy Consumption and Peak Demand for the year 2021. Peak consumption occurs on Summer and peak demand happens in the first quarter of the year. The consumption is breakdown in **Figures 4 and 5**.



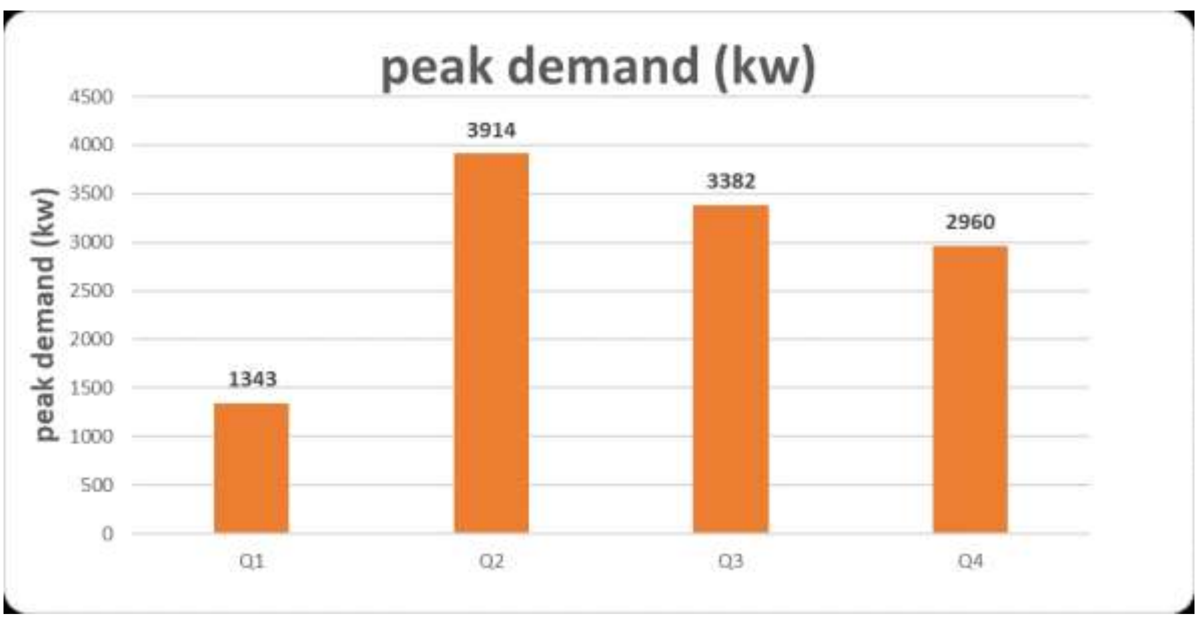
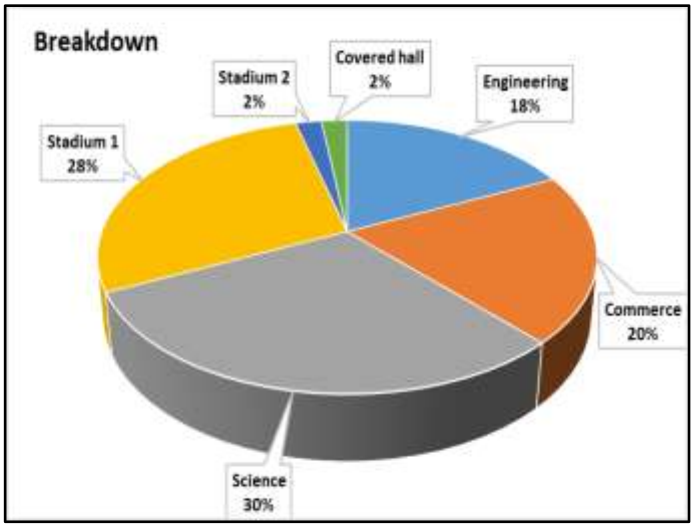


Figure 3 Electric Energy Consumption and Peak Demand for the year 2021



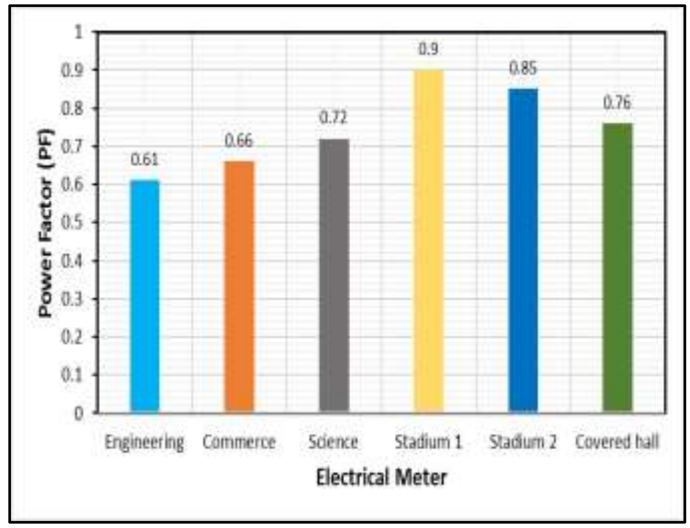


Figure 4 Average Power Factor Calculated for each meter **Figure 5 Consumption Breakdown by each meter**

Table 2 below summarizes the electricity bill information for the year 2021. The campus consumes around 7.8 TWh of electric energy with an average annual power factor of 0.78. This low power factor results in annual penalty of 750,883 EGP. The objective of the current work is to effectively reduce the campus electric consumption by applying Energy Efficiency Measures (EEMs) to it extent, raise the power factor to around 95 % to avoid the penalty, and to cover the remaining campus energy needs from a sustainable source like Solar PV panels. These three objectives will cover all the bill cost of 11,253,232 EGP and yield a carbon neutral sustainable campus which is the ultimate goal of this work.

Table 2 Electricity Bill for the Year 2021

The existing situation	
Total Consumption (kWh)	7,865,590
Cost for Consumption (EGP)	9,045,429
Cost for Maximum Peak (EGP)	1,456,920
Total Cost (EGP)	10,502,349
Power Factor	0.777
Penalty to the PF (EGP)	750,883
Total Bill (EGP)	11,253,232

Measurements of the Campus Daily Load Curve

- Loads are measured and averaged hourly through a week in each much. It is assumed that the pattern is repeated through the whole month
- The following **Figures 6-11** present the monthly load curves starting Nov. 2021 till June 2022.
- It is clear that the campus peak load occurs around noon which is perfect for the design of the solar PV as it matches the profile of the solar PV generation curve. This maximizes the benefit from the PV system and eliminates the needed for electricity storage. In addition, the majority of the campus consumption happens outside peak hours. So, switching to the TOU tariff system may be cost effective than using an average flat rate tariff.

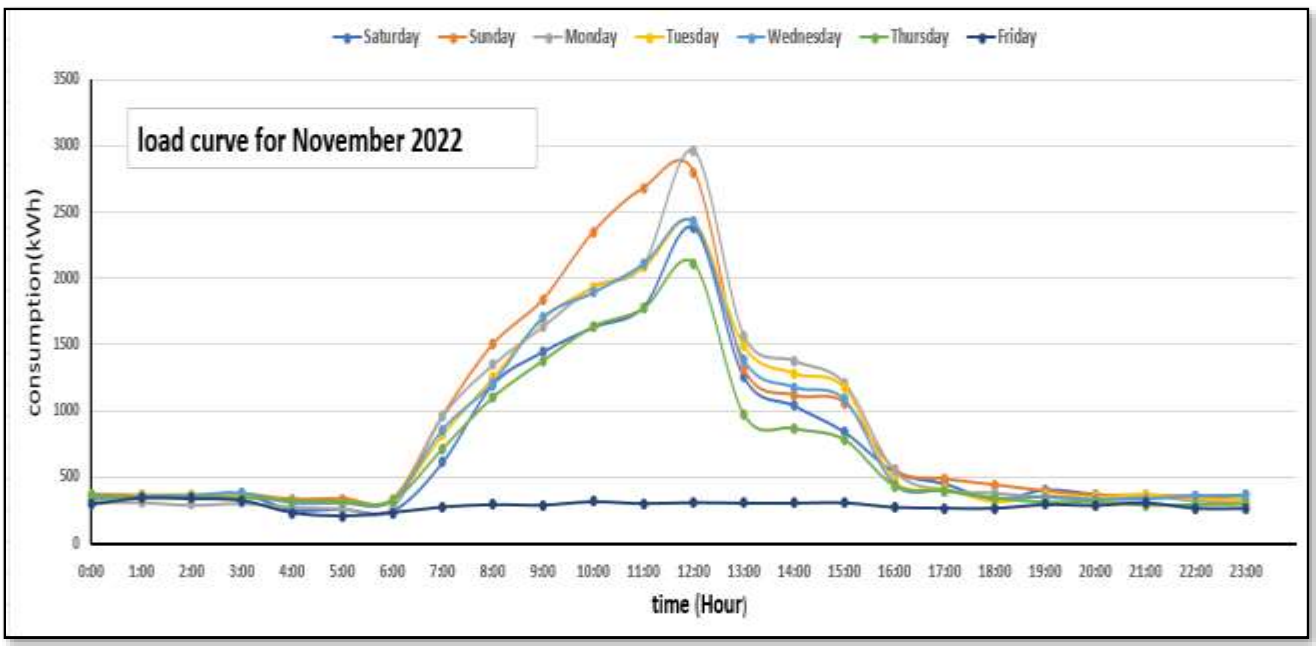


Figure 6 Load Curve for the Month of November 2021

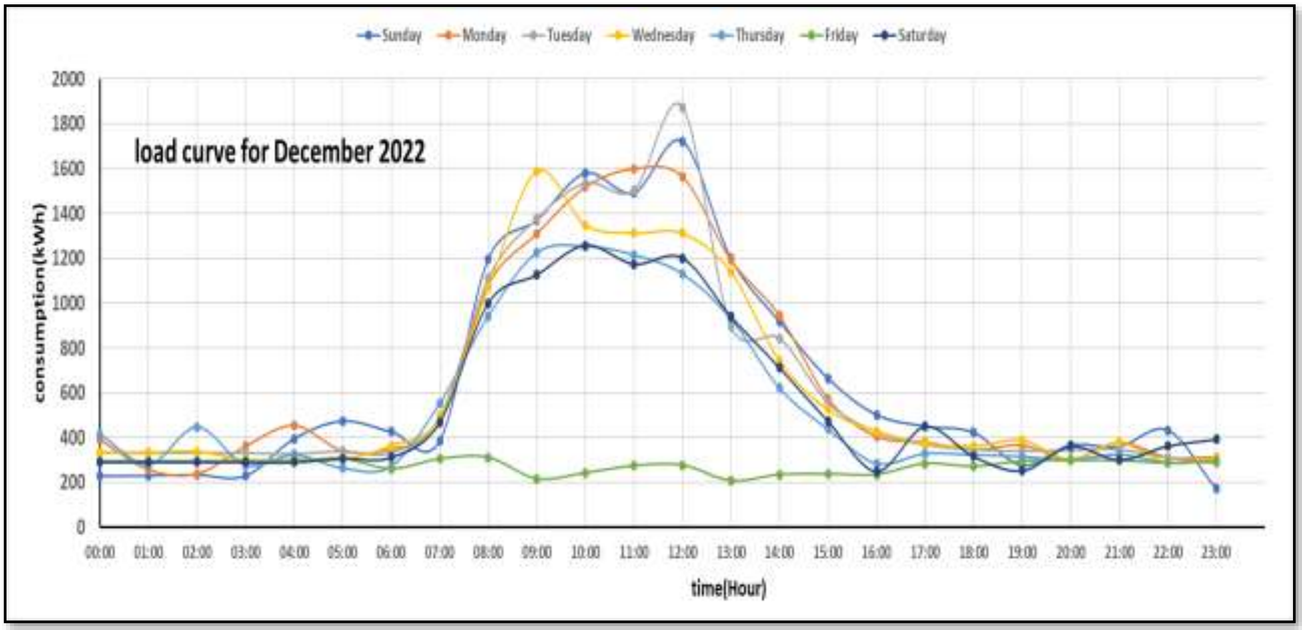


Figure 7 Load Curve for the Month of December 2021

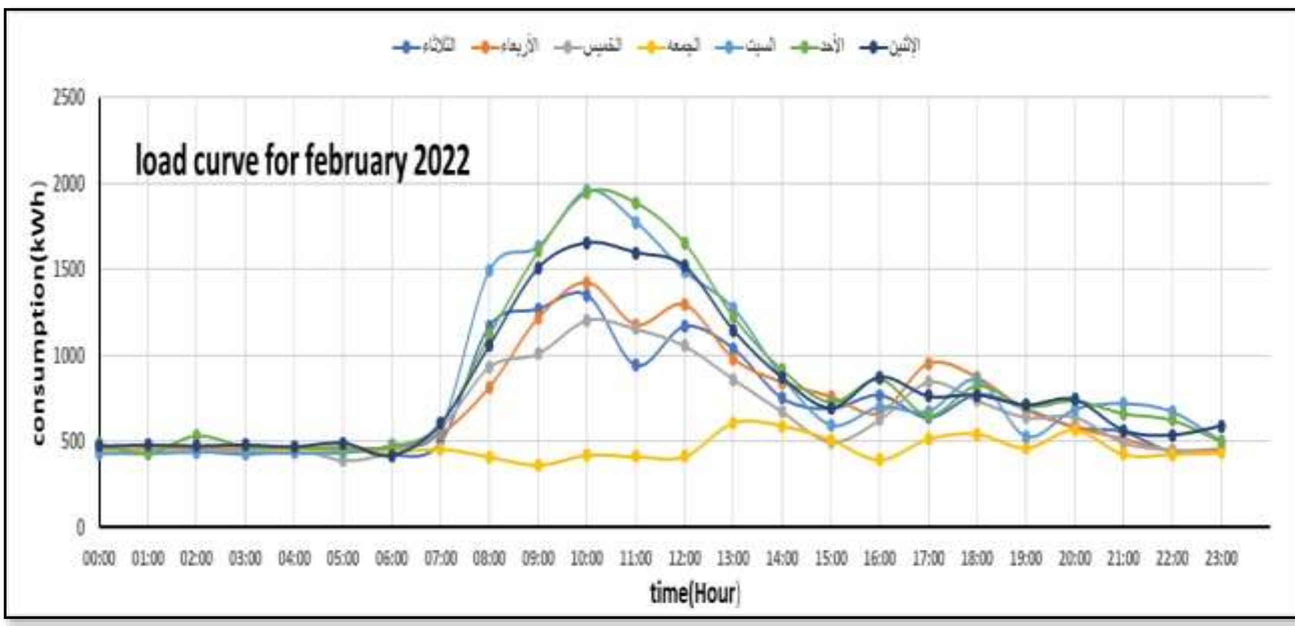


Figure 8 Load Curve for the Month of February 2022

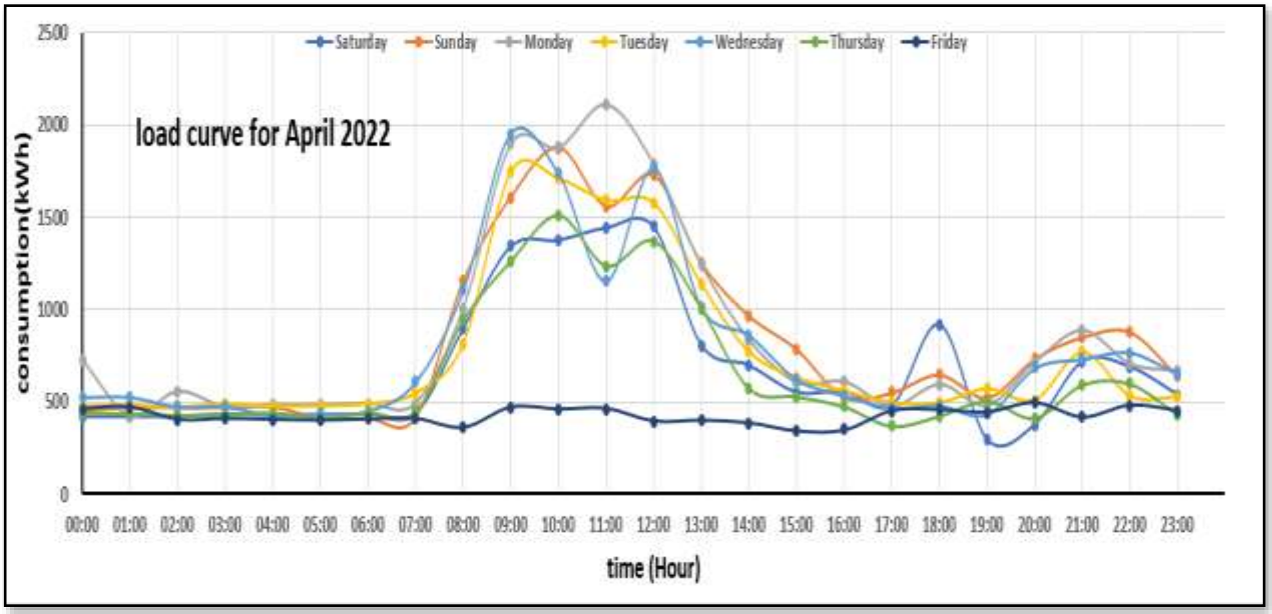


Figure 9 Load Curve for the Month of April 2022

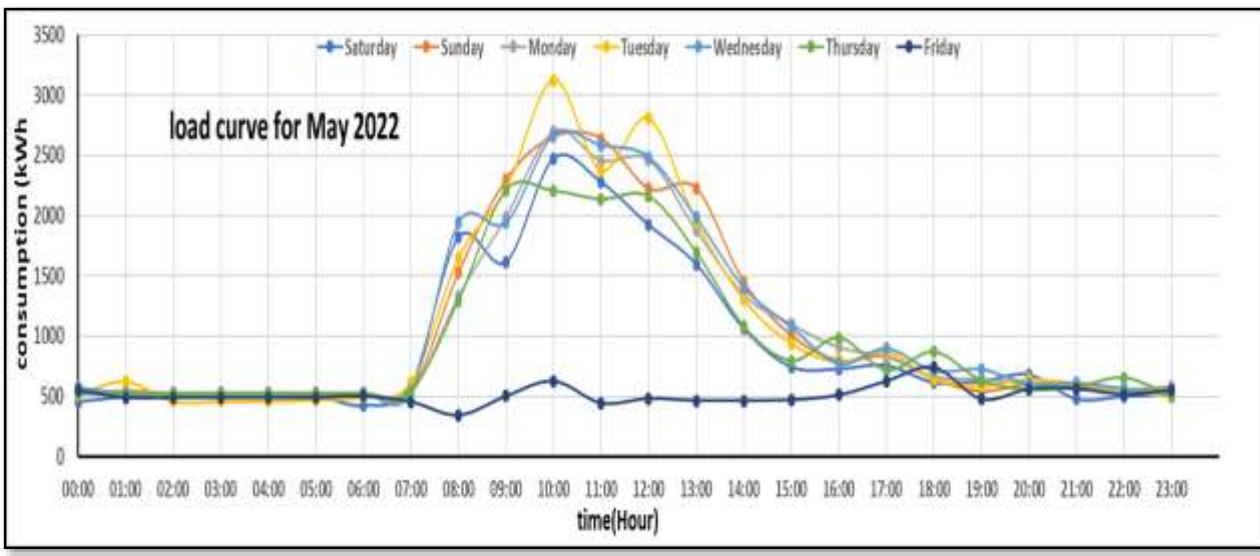


Figure 10 Load Curve for the Month of May 2022

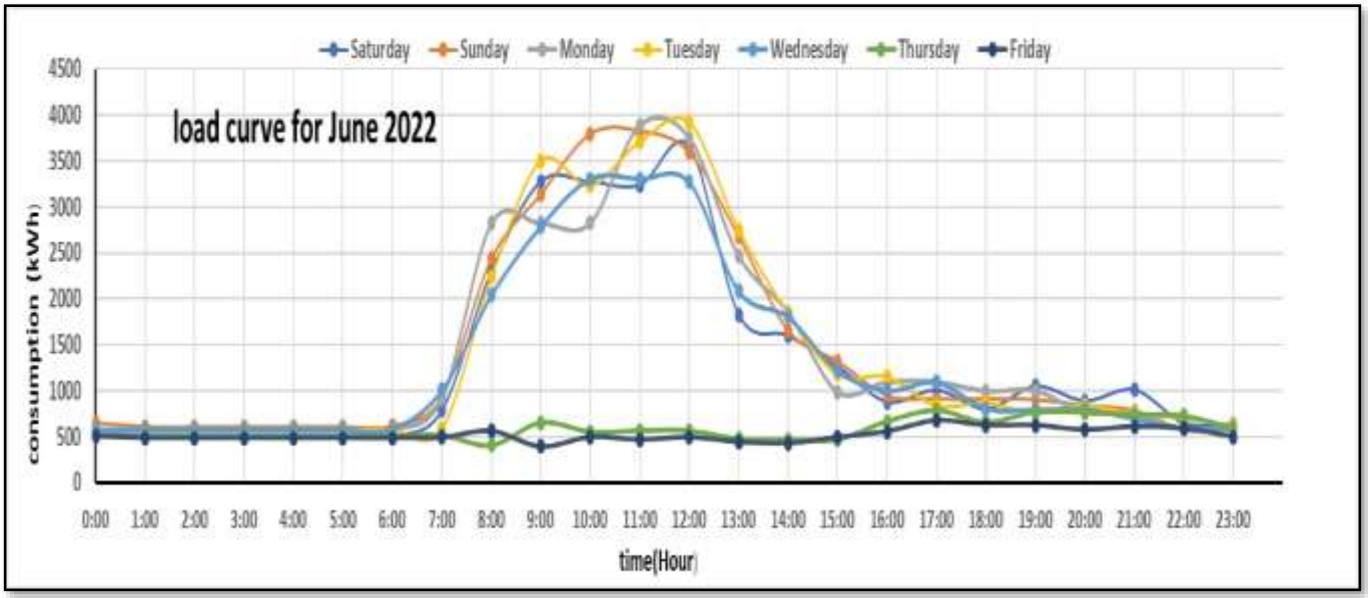


Figure 011 Load Curve for the Month of June 2022

Impact of Applying ToU Tariff

Changing the tariff from the existing two-part tariff to TOU tariff will provide an annual saving of **402,860 EGP** which equals **3.8%** saving from annual bill for the energy consumption. If the PF is improved, the total bill can be reduced more by **750,883 EGP.** Total reduction in bill = **1,153,743 EGP as in Figure 12 below.**

The existing situation	
Total Consumption (kWh)	7,865,590
Cost for Consumption (EGP)	9,045,429
Cost for Maximum Peak (EGP)	1,456,920
Total Cost (EGP)	10,502,349
Power Factor	0.777
Penalty to the PF (EGP)	750,883
Total Bill (EGP)	11,253,232

TOU Tariff	
On Peak Consumption (kWh)	545,872
Off Peak Consumption (kWh)	7,319,718
On Peak Cost (EGP)	869,028
Off Peak Cost (EGP)	7,773,541
Maximum Peak Cost (EGP)	1,456,920
Power Factor	0.777
Penalty due to PF (EGP)	750,883
Total Bill (EGP)	10,850,372

Figure 12 Comparison between the cost when using the Existing Tarif and the TOU Tariff

Section 2: Energy Efficiency Potential in The Campus Buildings

To optimize the system efficiency and to reduce the capital investment, campus loads are optimized and minimized through a comprehensive auditing process. Applying all possible energy efficiency measures (EEMs) to the campus budlings will result in around 30 % savings in annual energy consumption (around 2.24 TWh) with a Levelized cost of Electricity of 0.52 LE/kWh. This LCOE is remarkably lower than any other energy cost (Grid, Solar PV, …etc). This encourages all possible investment in that direction. The remaining campus energy needs of around of 5.35 TWh will be covered by the solar PV system as will be described later in Section 3.

Pattern of Electricity Consumption in Buildings (Sample of 6 buildings)

Since its building does not have its own power meter, it will be necessary to find a way to draw the system daily load curve for this individual building. This daily load curve will be the baseline for any energy efficiency measures applied later on during the auditing process. Three periods will be used for load evaluation: namely, working hours, late working hours, and overnight, as shown in Figure 13. The Pattern of Electricity Consumption for is studied in both Working and non-working Days to account for vacations. A sample of 6 buildings are selected for the preliminary evaluation. Five of the buildings are educational buildings with classrooms and one unique presidency building with administrative nature. Figure 13 shows that the Presidency (Administrative) building is the highest in electricity consumption over the day in working days. Figure 14 shows the same trend in non-working days.

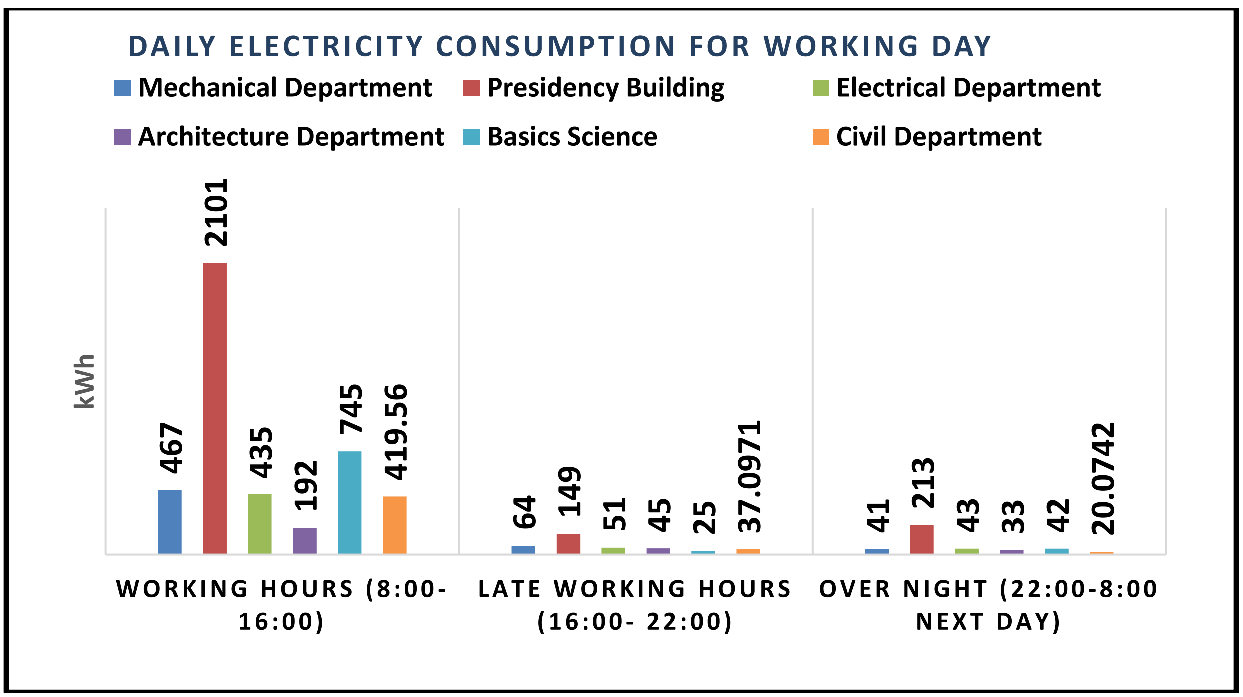


Figure 13 Pattern of Electricity Consumption for Working Days

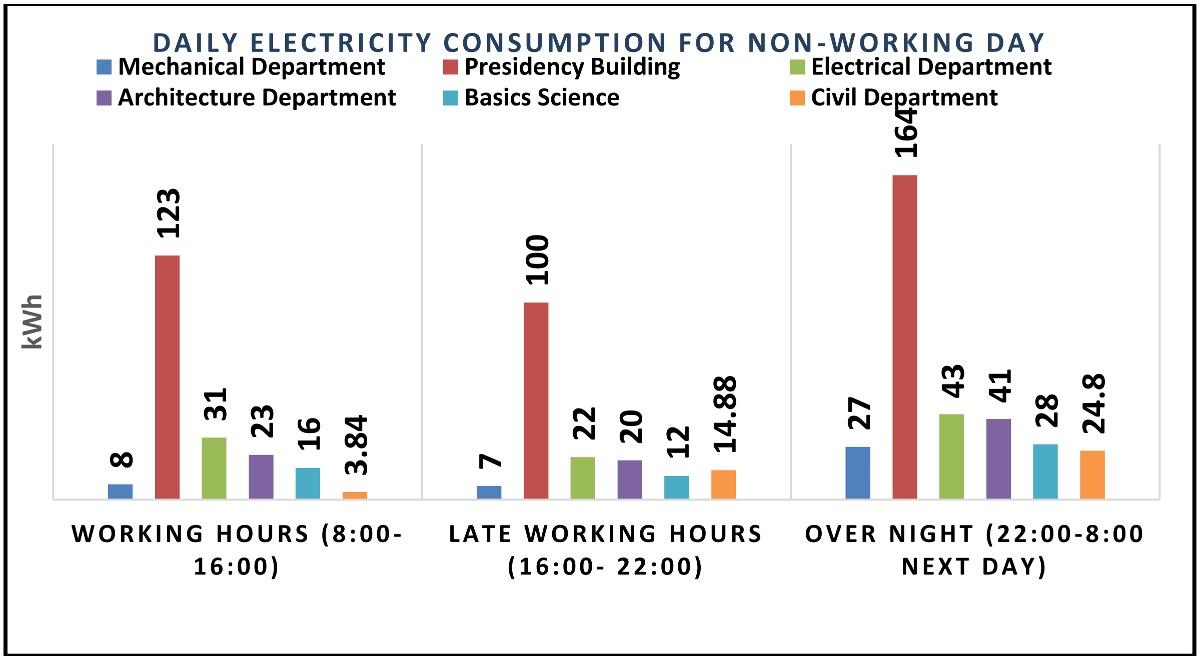


Figure 14 Pattern of Electricity Consumption for Non-Working Days

Breakdown for Annual Electricity Consumption

The breakdown of electricity consumption in the 6 studied buildings shows the share of every individual consumer to decide the significant energy user, SEU, as shown in Figure 15. Lighting is the most SEU in all buildings except for the residency (administrative) building which has significant amount of air conditioning (AC) loads.

Given the energy consumption and the available floor area for each building, it will be possible to calculate the energy intensity in each building. Table 3 shows the metrics for each building based on the estimated daily consumption. The presidency building has the highest energy intensity among the studied buildings (25.9 kWh/m^2). This metric will be used as a key performance indicator (KPI) for building energy use comparison and to prioritize the energy auditing process.

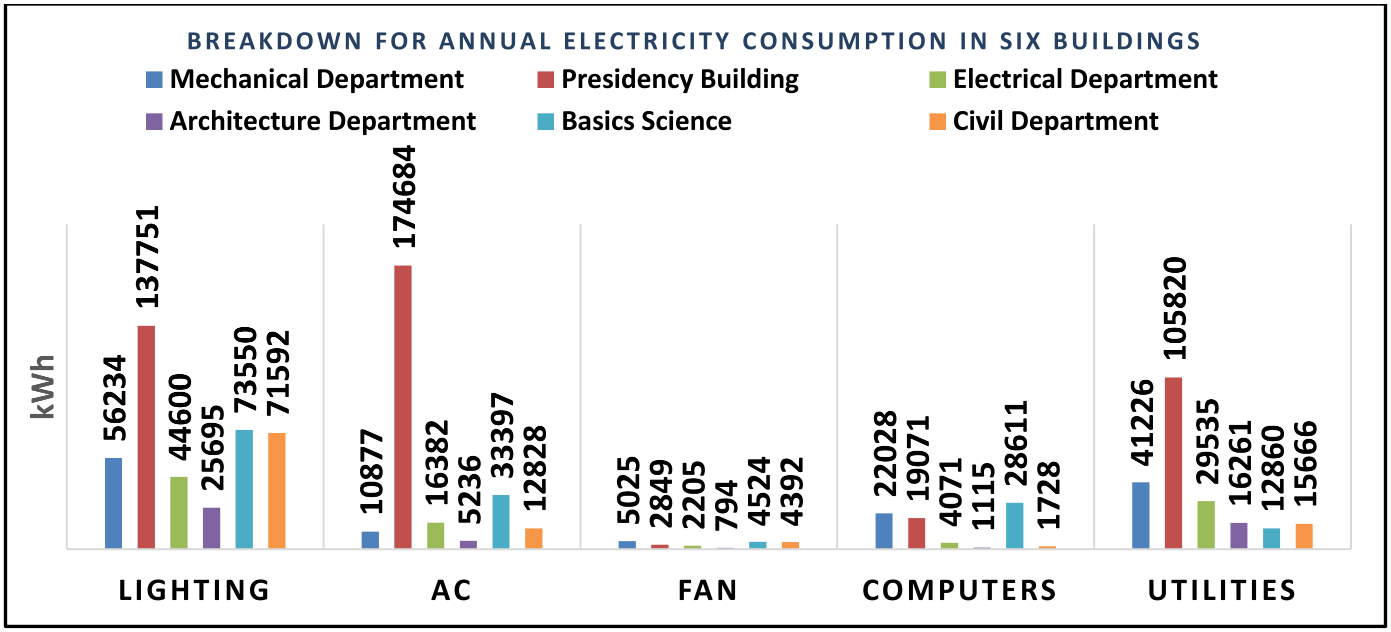


Figure 15 Breakdown for Annual Electricity Consumption

Table 3 Statistics of the studied buildings

	Mechanical Dept.	Presidency Building	Electrical Dept.	Arch. Dept.	Basic Science	Civil Dept.
Area (m^2)	1,160	3,400	1,300	1,050	2,740	1,355
Annual Elec. Cons.	136,169	440,176	103,240	54,688	163,172	109,125
Energy Intensity (kWh/m^2)	23.5	25.9	15.9	13	11.9	16.1

Since Lighting is the SEU in almost all the university buildings, special attention will be given to lighting loads. Site visits and walk-through auditing showed that the majority of the lighting systems are old fluorescent lamps. This is why the university average power factor is significantly low. Before deciding switching to LED systems, an extensive lab testing of all market available LED lamps is performed. Figure 17 shows the detailed testing results for both conventional and LED lamps of different types.

Lab Testing of market available brands (LED vs. Fluorescent)

LED (120 cm)								
	Brand Name	Venus	Venus (3 Steps)			Elios	ElSwedy	Tornado
Brand Specifications	Lifetime (hrs.)	30,000		30,000		30,000	25,000	30,000
	Power (Watt)	18		18		18	18	18
	Lumen	1800		1800		1950	1800	2000
Lab Measurements	Current (A)	0.14	0.14	0.06	0.02	0.09	0.08	0.08
	Power Factor	0.58	0.9	0.95	0.97	0.942	0.96	0.99

Fluorescent (120 cm)			
	Brand Name	**Philips**	**Tornado**
Brand Specifications	**Lifetime (hrs.)**	13,000	20,000
	Power (watt)	36	40
	Lumen	2370	2700
Lab Measurements	**Current (A)**	0.36	0.32
	Power Factor	0.517	0.58

LED (60 cm)					
	Brand Name	Venus	Elios	ElSwedy	Tornado
Lamp Specifications	Lifetime (hrs.)	30,000	30,000	25,000	25,000
	Power (watt)	9	9	9	9
	Lumen	855	950	900	1000
Lab Measurements	Current (A)	0.07	0.05	0.04	0.04
	Power Factor	0.578	0.93	0.987	0.950

Fluorescent (60 cm)		
	Brand Name	**Tornado**
Brand Specifications	**Lifetime (hrs.)**	12,000
	Power (watt)	20
	Lumen	1070
Lab Measurements	**Current (A)**	0.16
	Power Factor	0.568

Figure 16 Lab Testing of market available brands (LED vs. Fluorescent)

Lighting System Simulation and Redesign

- For Lecture Hall (M1) at Mechanical Dept. Building, the current lighting system is simulated using the software DILUX . The left handside contour map shown in **Figure 18** presents the current Lux distribution on the hall with an average of 650 Lux. Comparing this illumination level to the classroom standard of 300, it is clear that the lighting level is unnecessarily above the standard. In addition, all the 126 installed bulbs are of the fluorescent type with the very low power factor of around **0.56**. Redesigning the lighting system by de-lamping and switching to the LED type will definitely reduce the installed capacity, reduce the energy consumption, and improve the power factor while maintaining the standard illumination level. The righthand side simulated results showed a uniform Lux distribution with an average of 370 Lux using 64 LED bulbs only. This re-designed lighting system saves around 77 % of the current installed electric capacity. In addition, the power factor of these LED lamps will improve the power factor to above 92 % with no need for PF Correction methods as most loads are lighting.

Figure 17 Lighting System Simulation and Redesign

Financial Analysis for Six Buildings in the Study

Feasibility study is performed to ensure the profitability of the Energy efficiency retrofits. **Table 4** shows the results of each of the studied 6 buildings. Due to lighting system re-design in those 6 buildings, a total of 335,331 kWh can be saved annually, in addition to avoiding a power factor penalty and peak load reduction. This raises the annual monetary saving to a total of 645,553 EGP. This lighting system retrofit comes with an investment cost of 1,039,322 EGP and has a a LCOE of 0.52 EGP/kWh and very low payback period.

Table 4 Results of Financial Analysis for Six Buildings in the Study

	Capital Investment (EGP)	Annual Consumption before Energy Efficiency (kWh)	Annual Consumption after Energy Efficiency (kWh)	Annual Energy Savings (kWh)	Annual Energy Savings Cost (EGP)	Saving due to Power Factor Correction (EGP)	Saving due to Peak reductionn (EGP)	Total Savings (EGP)	LCOE (EGP)
Mechanical	163,460	96,112	60,734	35,378	40,685	16,014	17,468	74,167	0.53
Presidency Building	257,667	611,134	525,295	85,839	98,714	38,033	27,821	164,569	0.30
Electrical	125,377	91,464	62,782	28,682	32,985	12,740	12,603	58,328	0.77
Architecture	60,508	72,447	45,501	26,945	30,987	11,504	6,005	48,496	0.44
Basic science	231,520	208,509	133,360	75,150	86,422	34,230	24,150	144,802	0.61
Civil	200,790	172,706	89,369	83,337	95,838	38,154	21,198	155,190	0.49
Total	**1,039,322**	**1,252,373**	**917,041**	**335,331**	**385,631**	**150,675**	**109,247**	**645,553**	**0.52**

Potential Saving & Feasibility of Energy Efficiency Opportunities at Zagazig University Campus (Projected)

Projecting the energy savings to the remaining of the campus results in around 2.23 TWh annual energy savings which represents around 30 % of the total annual energy consumption as detailed in **Table 5**. This EE saving comes with a LCOE of 0.52 LE/kWh encouraging all possible investment in that direction. The remaining campus energy needs of around of 5.3 TWh will be covered by the solar PV system as will be described later in Section 3.

Table 5 Potential Saving & Feasibility of Energy Efficiency Opportunities at Zagazig University Campus (Projected)

Capital Investment	**9,232,421**	**EGP**
Annual Electricity Saved	2,235,453	**kWh**
Annual Cost of Electricity Saved	2,570,771	**EGP**
Simple Payback period	3.4	**Year**
Discounted Payback Period	4.0	**Year**
Internal Rate of Return	31%	
Net Present Value	15,580,990	**EGP**
Levelized Cost of Electricity	0.52	**EGP**

Section 3: Solar PV Supply System to Zagazig University Campus

The design and simulation is done using a set of professional licensed software packages. The system design starts with projecting the campus plan areas using Google Earth and AutoCAD. This helps in categorizing the campus into different layers for estimation of available surface area for PV installation. The 3D projection of all buildings is done using Sketch-up with the assistance of height measurements of each building. At this level of work, all possible roof areas can then be calculated. To effectively lower the shading losses results from roof shadowing, the shading analysis is performed using **CURICSUN** shadow simulation tool. This tool gives the net roof area results in minimum shadow over the panel.

Site Assessment

The system design starts with projecting the campus plan areas using Google Earth and AutoCAD as shown in Figures 19 and 20, respectively. This helps in categorizing the campus into different layers for estimation of available surface area for PV installation

Google Earth Pro.

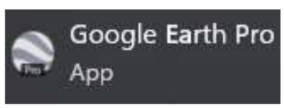


Figure 18 Campus Map by Google Earth Pro

AutoCAD 2020

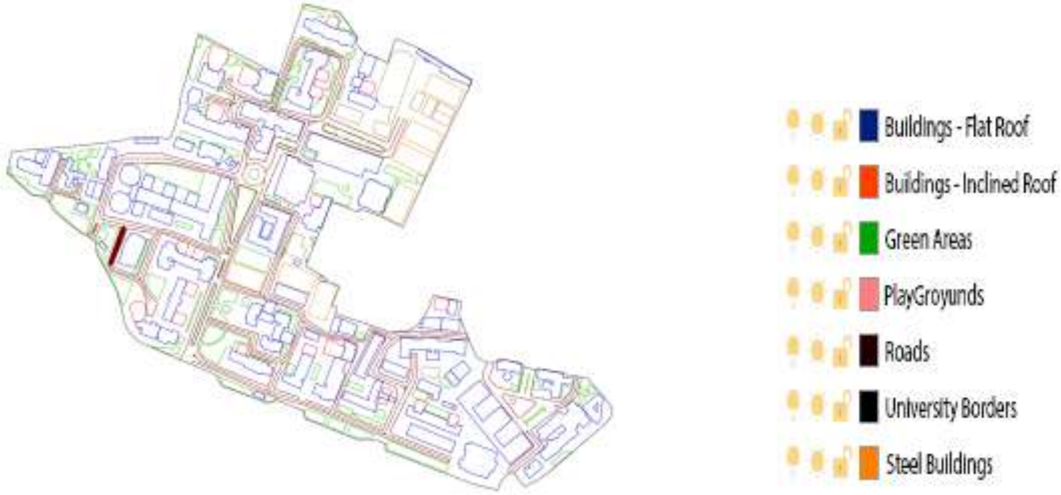


Figure 19 Campus Map (2D) by AutoCAD

3-D Modeling

The 3D projection of all buildings is done using Sketch-up with the assistance of height measurements of each building. This is necessary to decide the tilted roofs and the shadows on buildings as shown in Figure 21.

SketchUp

Figure 20 Campus 3D Modelling using Sketchup

Shadow Simulation CURICSUN

The shading analysis is performed using **CURICSUN** shadow simulation tool. This tool gives the net roof area results in minimum shadow over the panel as shown in Figure 22. The day of December 21 is known with its longest shadow. This is simulated as shown in Figure 23 at 9:00 am.

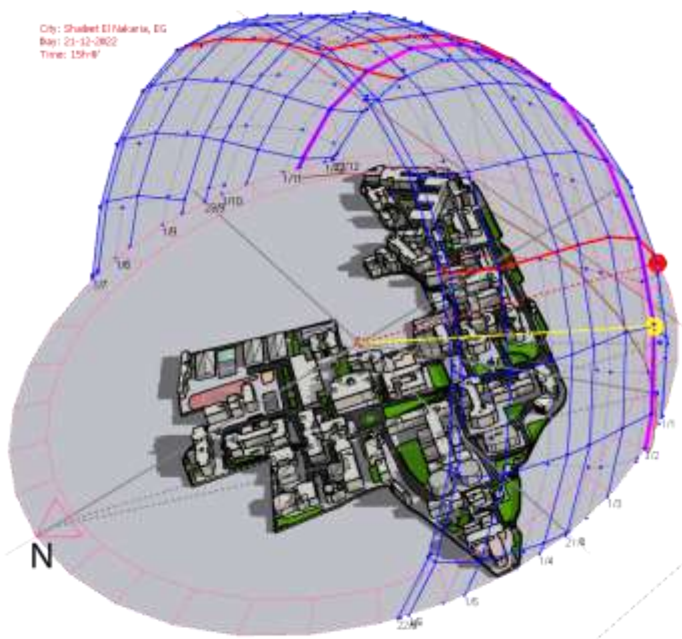


Figure 21 Shadow Simulation using CURICSUN

Shadow Simulation on Dec 21 at 09.00 AM

Figure 22 Shadow Simulation on Dec 21 at 09.00 AM (Longest Shadow over the year)

PV Modeling & Simulation

Skelion plugin for SketchUp

The Skelion plugin in Sketup is sspecially developed to insert solar panels in any roof. It is used to insert solar panels in areas with minimum shading as shown in Figure 24.

Figure 23 PV Simulation using Skelion plugin for SketchUp

PV Modeling & Simulation

Results of the simulation

- **Using PVWATTS**
- **The proposed plant Capacity = 3,302 kWp.**
- **Number of Module Panels = 7,591**
- **Annual Yield = 5,349,000 kWh**

The PV System monthly predicted energy output (kWh) for the whole campus is presented in Figure 25 below. The peak production occurs in Summer due to the higher solar radiation.

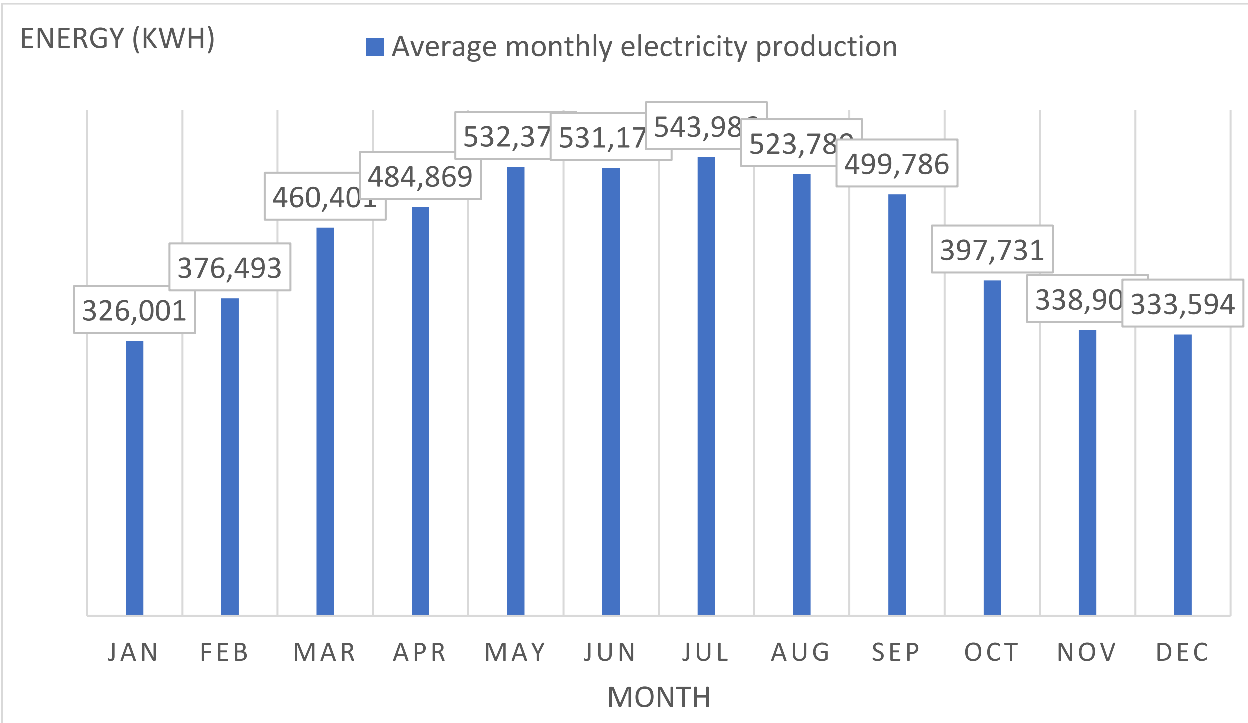


Figure 24 PV System predicted output for the whole campus

Financial Analysis

Continuing the design using this net roof are results is a solar PV system with an installed Capacity of 3,3 kWp (number of Module Panels is 7,591) that has an annual yield of around 5.35 TWh. This annual solar PV yield is supplying the campus with all what it needs with a Levelized cost of Electricity of 0.83 LE/kWh (with merging cost included) as detailed in Table 6

Table 6 Financial Analysis for the Campus PV system project

PV Installed Capacity	**3,300**		**kWp**
kW Price	13, 000		**EGP**
Investment cost	**42,900,000**		**EGP**
Annual operating hours	**1621**		**Hours**
Annual electricity saved	**5,349,000**		**KWh**
Electricity cost	**1.15**		**EGP**
Annual cost of electricity saved	**6,151,350**		**EGP**
Annual labor cost	**0**		**EGP**
Merging cost	**0.257**		**EGP/K**
Annual material cost	**2%**		
Material price index	**10%**		
The rate of deterioration	**0.50%**		
Discount rate	**9%**		
Project life time	**25**		
Electricity escalation rate	**5 %**		
Labor wages annual growth rate	**10%**		
Income tax rate	**0%**		
Peak demand reduction saving	**911,880**		**EGP**
Overall annual saving	**7,063,230**		**EGP**
Financial Indicators	With Merging Cost	Without Merging Cost	
Simple Payback Period	**8.88**	**6.91**	**years**
Discounted Payback Period	**11.26**	**8.71**	**years**
Internal Rate of Return	**15.06%**	**17.92%**	
Net Present Value	**27,726,336**	**40,716,329**	**EGP**
Annualized Cash Flow	**2,822,714**	**4,145,177**	**EGP**
LCOE	**0.83**	**0.66**	**EGP**

Section 4: Optimum Supply System of Zagazig University campus

Optimum Supply System of ZU campus (Summary)

- Based on the **projected** Energy Efficiency Savings for the whole campus and the designed and simulated PV output, the optimum mix for the campus will be as in **Figure 25**.
- Energy efficiency Measures (EEMs) save **2,235,453 kWh** (30 % from campus electricity consumption) with LCOE 0.52 EGP/kWh. Annual Monetary Savings **2,570,771 EGP.**
- PV systems will generate **5,349,000 kWh** (70% of the electricity consumption) with LCOE 0.83 EGP/kWh including the merging cost or LCOE 0.66 EGP/kWh when waiving the merging cost. Annual Monetary Savings **6,151,630 EGP.**

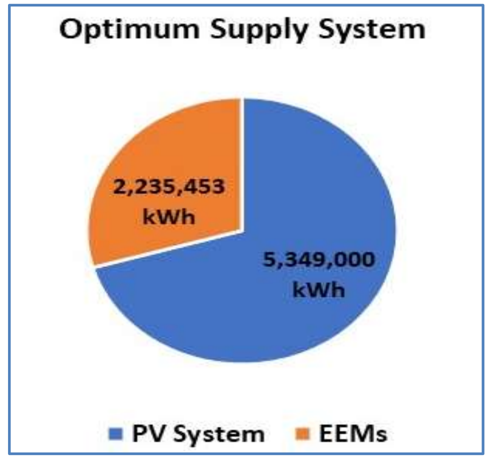


Figure 25 Optimum Supply System of ZU campus

- Power factor enhancement (from 77.7% to 95%) comes with annual penalty saving of **886, 452 EGP**.
- Peak demand reduction as a result of energy efficiency and PV system installation results in annual saving of **1,436,256 EGP**.
- Total Annual Project Savings **11, 045, 109 EGP**
- The **Annual CO_2 saving** is **3,510 ton CO2.**
- The whole project needs a total investment of (52,132, 421 EGP) for both energy efficiency (9,232,421 EGP) and PV installation system (42,900,000 EGP). It financially feasible and attractive with a SPB of 6 years and IRR of 21.3 % **even with including the merging cost of 0.257 LE/kWh**. Without including the merging cost, the project becomes more attractive. The payback period decreases to **5.2 years and Internal Rate of Return increases to 23.6 % (**increases by 10.7 %) for same financial parameters

Details of The Project Savings and Financial Feasibility

Reduction in Peak Demand due to Energy Efficiency (EE) and PV installation

Since the Tariff system is two-part tariff, the peak demand reduction results in an extra reduction in the electricity bill. Figure 27 shows the peak reduction in the campus daily load as a result of applying EE Measures with PV system installation.

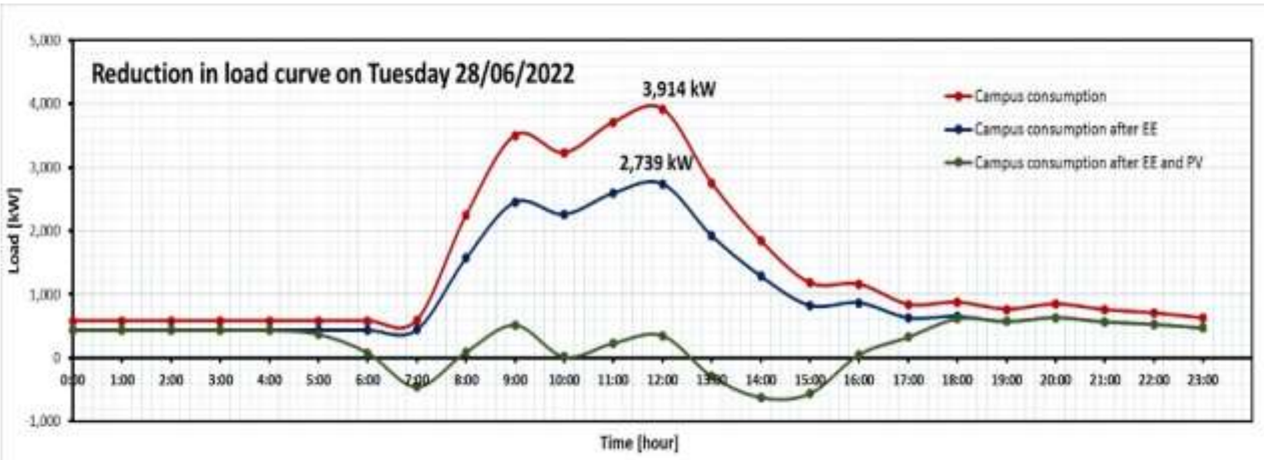


Figure 26 Reduction in Peak Demand due to Energy Efficiency (EE) and PV installation

Summary of reduction in peak demand due to EE & due to EE and installing PV.

Detailed predicted monthly reduction in peak demand as a result of applying EE measures and PV installation are shown in Table 7.

Table 7 Summary of reduction in peak demand due to EE & due to EE and installing PV

MONTHS	max peak demand before EE (kW)	max peak demand after EE (kW)	Max peak demand after EE and using PV (kW)
November	2960.0	2072	1211
December	1873.0	1311.1	370
February	1343.0	940.1	233.6
April	2115.0	1480.5	690
May	3124.0	2186.8	639.4
Jun	3914.0	2739.8	788

Annual saving due to reduction in peak demand

A total annual saving of **1,436,256 EGP** is expected due to the Energy Efficiency Measures and the PV system installation as detailed in Table 8.

Table 8 Annual saving due to reduction in peak demand

Saving due to reduction in peak demand				annual saving (EGP)
winter	Fall	summer	spring	
199692	562680	359064	314820	1,436,256.0

Total Expected Savings from The Whole Campus Project

The sustainable campus project saves **2,235,453 kWh** in energy and **11,045,109 EGP** in electricity payments each year as shown in Table 9.

Energy efficiency

ZU campus electricity consumption can be saved by 2,235,453 kWh due to energy efficiency measures (EEMs).

Money saving

Comes from energy efficiency measures (basically the re-design of the lighting system), power factor enhanced (basically due switching to high power factor LED lamps), PV annual savings, and peak demand reduction.

Table 9 Total Expected Savings from The Whole Campus Project

Energy EE	2,570,771	EGP
Power Factor enhancement	886,452	EGP
PV Annual Saving	6,151,630	EGP
Peak demand reduction (both EE and PV)	1,436,256	EGP
Total	11,045,109	EGP

Emission saving

In addition to the monetary savings, the project comes with extra environmental benefit. According to Electricity Observatory report, March 2022, CO_2 emission from power plants is around 446.23 [gm CO_2 /kWh]. Due to the avoided burnt fuel, the **Annual CO_2 saving** is **3,510 ton CO2.**

Summary of Financial Analysis

The following Table 10 show the inputs for the financial study for the PV system and the EE measures projected for the whole campus. The whole project needs a total investment of (52,132, 421 EGP) for both energy efficiency (9,232,421 EGP) and PV installation system (42,900,000 EGP). It financially feasible and attractive with a SPB of 6 years and IRR of 21.3 % even with adding a merging cost of 0.257 EGP/kWh. Without including the merging cost, the project becomes more attractive. The payback period decreases to **5.2 years and Internal Rate of Return increases to 23.6 % (**increases by 10.7 %) for same financial parameters

PV System Inputs

Table 10 Summary of Financial Analysis for the Campus Project

PV Installed Capacity	**3,300**	**kWp**
kW Price	**13,000**	**EGP**
Investment cost	**42,900,000**	**EGP**
Annual operating hours	**1621**	**Hours**
Annual electricity saved	**5,349,000**	**KWh**
Electricity cost	**1.15**	**EGP**
Annual cost of electricity saved	**6,151,350**	**EGP**
Annual labor cost	**0**	**EGP**
Merging cost	**0.257**	**EGP/kWh**
Annual material cost	**2%**	
Material price index	**10%**	
The rate of deterioration	**0.50%**	
Discount rate	**9%**	
Project life time	**25**	
Electricity escalation rate	**5%**	

Labor wages annual growth rate	**10%**	
Income tax rate	**0%**	
Peak demand reduction saving	**1,436,256.00**	**EGP**
Overall annual saving	7,587,606	**EGP**

Energy Efficiency Inputs

Energy Efficiency Inputs		
EE investment/kWh	**4.13**	**EGP/kWh**
Annual Electricity Saved from EE	**2,235,453**	**kWh**
EE investment	**9,232,421**	**EGP**
Annual Electricity Saved from EE	**2,570,771**	**EGP**
penalty of power factor (will be saved)	**9.80% (886, 452 EGP)**	

Total		
investment	**52,132, 421**	**EGP**
annual saving	**11,045,109**	**EGP**
Annual Material Cost	**1,042,648**	**EGP**
Material Price Index	**10.0%**	
Income Tax Rate	**0.0%**	
Discount Rate	**9.00%**	

Total Financial Indicators			
	With Merging Cost	**Without Merging Cost**	
Simple Payback Period	**6.04**	**5.21**	years
Discounted Payback Period	**7.05**	**6.1**	years
Internal Rate of Return	**21.33 %**	**23.62 %**	%
Net Present Value	**73,432,051**	**86,422,044**	EGP
Annualized Cash Flow	**7,475,842**	**8,798,304**	EGP
Levelized cost of energy/kWh	**0.52**	**0.41**	EGP

Sensitivity Analysis

The effect of escalation of several variables on the project profitability is studied. Here is the list of studied variables

- The effect of PV investment cost (**42,900,000** ± 10%)
- Effect of electricity escalation rate (2% and 5 %)
- Effect of merging cost (included or excluded)

Based on sensitivity analysis for different PV variables, PV CAPEX change is the most influencing parameter on the project profitability. Increasing PV investment cost by 10 % (with merging cost included) will decrease the NPV and the IRR by 56% and 13.5%, respectively. **Without including the merging cost**, the project profitability is greatly enhanced. The NPV and the IRR will increase by 17.7 % and 10.7 %, respectively. The effect is symmetrical in the direction of the decrease as well.

Regarding the electricity escalation rate, the higher the escalation rate the better is the project profitability. Doubling the electricity escalation ate will increase the IRR by more than 30 % and will triple the NPV.

Summary and Conclusions

The report presented a snapshot of the work done in the project "**Towards A Sustainable Zagazig University Campus**" at Zagazig University, Egypt. The project aims at optimizing the energy supply system to ensure a carbon neutral campus with minimum dependence on the grid and with a sustainable source of electricity through a solar PV system. To optimize the system efficiency and to reduce the capital investment, campus loads are optimized and minimized through a comprehensive auditing process to apply all possible energy efficiency measures (EEMs). This auditing process is required since it's not logic or economic to feed an inefficient load from a costly Solar PV system. The solar PV system will then be designed to cover the remaining campus loads in an efficient way.

Its worthy to mention that the current work has started as a B.Sc. Graduation Project for 4th year senior students, and then evolved to be the University Goal for the Sustainable Campus. So, it's not strange to know that most of the tasks were performed by senior mechanical engineering students with minimum directions from the faculty staff and assistants. In addition, there is a 105 kWp grid-connected solar PV system designed, commissioned, installed, and operated by the same work group at the faculty of engineering a year before the start of this work. This small system is the nucleus for the big system that will feed the whole campus, and the acquired knowledge and experience was the prime mover for the current project. In Appendix A, a full monitoring report on the performance of the 105 kWp system is introduced along with the acquired lessons and experiences gained throughout the year-long service of the system. This acquired experience will ensure the sustainability and operability of the whole campus PV system.

The report was divided into **Four sections** to reflect the four basic tasks performed during the work.

Section 1 presented background information about the campus, floor areas, electric loads measurements, and current electricity consumption and Tariff. The investigation of the Single Line Diagram and the analysis of the Electricity Bills for the ZU Main Campus showed that the total electricity bill for the year 2021 was 11,00000 EGP. The applied tariff is **two-part** with 1.15 LE/kWh for medium-voltage energy consumption and 60 LE/kW for peak load. There is a **750,883**

EGP Power Factor penalty (for PF ≈ 0.78 < 0.92). Initial inspection showed that changing the tariff from the existing two-part tariff to TOU tariff will provide an annual saving of 402,860 EGP which equals 3.8% saving from annual bill for the energy consumption. If the PF is improved, in addition, the total bill reduction can reach 1,153,743 EGP**.** Measurements of the Campus Daily Load Curve showed that the campus peak load occurs around **noon** which is perfect for the design of the solar PV as it matches the profile of the solar PV generation curve. Accordingly, the following sections with investigate the potential of energy savings due to the reduction of the campus peak load and energy consumption, improving the power factor, and installing the solar PV system to cover the remaining needs of the campus.

Section 2 presented Energy Efficiency Potential in The Campus Buildings. As mentioned above, its necessary to optimize the campus's energy system efficiency to reduce the capital investment of the installed PV system. Campus loads are optimized and minimized through a comprehensive auditing process. Applying all possible energy conservation measures (ECMs) to the campus buildings will result in around **30 %** savings in annual energy consumption (around **2.24 TWh**) with a Capital Investment of 9,232,421 EGP and Levelized cost of Electricity of 0.52 LE/kWh. This LCOE is remarkably lower than any other energy cost (Grid, Solar PV, …etc). This encourages all possible investment in this direction to fully make use of the energy efficiency opportunities. The remaining campus energy needs of around of **5.35 TWh** will be covered by the solar PV system as it follows in the LCOE as will be described in Section 3.

Section 3 presented the Solar PV Supply System to Zagazig University Campus. The design and simulation were done using a set of licensed professional software packages. The system design starts with projecting the campus plan areas using Google Earth and AutoCAD. This helps in categorizing the campus into different layers for estimation of available roof areas for the PV system installation. The 3D projection of all buildings is done using Sketch-up with the assistance of height measurements of each building done by the group buildings. Height measurements helped the crew to identify the sloped surfaces and it will be essential in shading calculations. At this level of work, all possible roof areas can then be calculated. To effectively lower the shading losses results from roof shadowing, the shading analysis is performed using **CURICSUN** shadow simulation tool. This tool gives the net roof area results in minimum shadow over the panel. Continuing the design using this net roof are results is a solar PV system with an installed Capacity of 3,302 kWp (number of Module Panels is 7,591) that has an annual yield of around 5.35 TWh. This annual solar PV yield is supplying the campus with all what it needs with a Capital Investment of 42,900,000 EGP and Levelized cost of Electricity of 0.83 LE/kWh (with merging cost included).

Section 4 introduced a **Projection** for the Optimum Supply System of Zagazig University campus along with the financial and feasibility study performed for the EEMs and PV system. The predicted optimum cost effective supply mix will be around 30 % from EEMs and 70% from the PV system. This mix ensures the lowest investment PV system cost, the minimum system operating cost, and the best economic feasibility. Total investment of (52,132,420 EGP) is required for both energy efficiency (9,232,421 EGP) and PV installation system (42,900,000 EGP). The total monetary savings from the project will be 11, 045, 109 EGP coming from applying the EEMs (2,570,771 EGP), installing the PV system (6,151,630 EGP), the peak load charges reduction (1,436,256 EGP), and avoiding the power factor penalty (886, 452 EGP). The project is economically feasible and attractive based on a payback period of **6 years** and the **Internal Rate of Return (IRR)** of **21.3 %** even with including the merging cost of 0.257 EGP/kWh. Without including the merging cost, the project becomes more attractive. The payback period decreases to **5.2 years** and the **IRR increases to 23.6 % (**increases by 10.7 %) for same financial parameters. This ensures a sustainable carbon neutral campus with an annual **CO_2 saving** of **3,510 ton**.

Appendix A: Performance monitoring of the pilot 105 kW installed PV system run and sustained by Faculty of engineering, Zagazig University. Zagazig university managed to have this pioneer demonstration project as the first sustainable university in Egypt and it inspired the working team to extend the vision to the whole campus. This small 105 kW system will be the nucleus for the whole carbon neutral sustainable campus. In this appendix, a detailed analysis of the system design, planning, feasibility, commissioning, and performance monitoring is provided. More important, it provides the learnt lessons from running and maintaining the 105 kW system. This will help maintaining and sustaining the future whole campus system.

University Vision to keep and Maintain the System is developed based on the previous experience of running the pilot 105 kW system. Actually, it's a learning process that developed over the year of servicing and monitoring the system. Since the major problem of the 105 kW system was the need for frequent and continuous cleaning of the system, students can be involved in this process within their free time with supervision from the university's energy efficiency unit. It is planned to offer a paid student working hours to those interested students. In addition to the financial benefit that they will get from doing that, student participation will have the benefit of raising the awareness of a big class of the campus community. This will extend the university's sustainability vision to the outside community as well. Finally, the university has an ambitious plan to apply for the ISO 50001 for energy management system. This will confirm the university's commitment to keep the environment, maintain a sustainable campus, and to continue in the energy utilization improvement plan.

The External benefits of installing the campus PV system is exceeding achieving the campus carbon neutrality and sustainability. The University has an ambitious plan of exploiting the system to its full extent. The experience obtained in designing and running the system will enable the university to run as an excellence center providing expertise and knowledge in solar PV design and installation. This really matches the governmental and global interests of sustainability and energy efficiency. In addition, It is planned that the energy efficiency unit at ZU will provide consultancy and supervision services of installing similar systems on governmental and private organizations along with monitoring and performance evaluation. **Society and community engagement** is not overlooked in ZU's vision. It is intended to provide free educational and instructional workshops to raise the awareness of the importance of energy efficiency and sustainability. Capacity building of knowledgeable engineers and operators of similar PV systems is one of the goals of the energy efficiency unit at ZU. Furthermore, high school students' visits and activities is planned as well. Its worthy to mention that faculty of engineering has an extended experience in dealing with STEM students and participating in their activities. This will broaden the exposure of pre-university students to such amazing experience of learning about PV systems in real life in addition to monitoring the performance of an already exiting system. Overall, the campus PV system will be the focus of many social engagement activities.

Appendices

Appendix A

Performance Monitoring of the 105 kW installed PV system run and sustained by Faculty of engineering, Zagazig University.

Zagazig university managed to have this pioneer demonstration project as the first sustainable university in Egypt and it inspired the working team to extend the vision to the whole campus. This small 105 kW system will be the nucleus for the whole carbon neutral sustainable campus. In this appendix, a detailed analysis of the system design, planning, feasibility, commissioning, and performance monitoring is provided. More important, it provides the learnt lessons from running and maintaining the 105 kW system. This will help maintaining and sustaining the future whole campus system. The picture below is taken by a drone flying over the installation sites of the system.

Download the full version of the Performance Monitoring report from **here**