Assessment of Carbon Neutrality and Sustainability in a University Campus through Evaluation of Energy Efficiency and Renewable Energy Potential of Academic Buildings

By

Rafia Akbar

105737

Session 2016-18

Supervised by

Dr. Muhammad Bilal Sajid

A Thesis Submitted to the US-Pakistan Center for Advanced Studies in Energy in partial fulfillment of the requirements for the degree of

MASTER of SCIENCE in

ENERGY SYSTEMS ENGINEERING

US-Pakistan Center for Advanced Studies in Energy (USPCAS-E)

National University of Sciences and Technology (NUST)

H-12, Islamabad 44000, Pakistan

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February 2019

Thesis Acceptance Certificate

Certified that final copy of MS/MPhil thesis written by Miss Rafia Akbar (Registration No. 105737), of U.S Pakistan Center for Advanced Studies in Energy, has been vetted by undersigned, found complete in all respects as per NUST Statues/Regulations, is within the similarity indices limit and is accepted as partial fulfillment for the award of MS/MPhil degree. It is further certified that necessary amendments as pointed out by GEC members of the scholar have also been incorporated in the said thesis.

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Date: _____________________________________

Certificate

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Abstract

Energy management in educational institutes needs to be improved in order to enhance their sustainability performance thus reducing the environmental footprint. This work aims to address this issue by conducting energy audits of academic buildings in a university campus located in Islamabad. These audits are conducted to analyze energy consumption of buildings and identifying possible sources of energy wastage and inefficient practices. As a result, measures were proposed to reduce electricity and fuel usage which will provide savings in operating costs of a building. Grid-connected solar photovoltaic (PV) systems are designed using HelioScope software for rooftops and parking lots of buildings to meet their electricity demand. Key performance metrics evaluated are monthly energy generation, performance ratio and kWh/kWp. Financial analysis of these PV systems is carried out using System Advisor Model (SAM) to calculate payback period, net present value and levelized cost of electricity. The results indicate that the proposed PV systems can meet a significant portion of the electricity demand of each building and have relatively short payback periods. Offsetting expensive grid electricity, most of which comes from thermal powerplants, will provide both environmental and economic benefits to the university.

Keywords: Academic Buildings, Energy Consumption, Energy Management, Energy Audits, Solar Photovoltaic System

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1. Qamar, A., **Akbar, R.**, Sanghvi, A., Bednarzhevskiy, A., Liu, L., Raj, A., Tatapudi, S., TamizhMani, G., Sundaramoorthy, R., Metacarpa, D., 2018. Outdoor performance of CIGS modules at multiple temperatures over three years, in: Munday, J.N., Bermel, P., Kempe, M.D. (Eds.), New Concepts in Solar and Thermal Radiation Conversion and Reliability. SPIE, p. 39. https://doi.org/10.1117/12.2326702
2. **Akbar, R.**, Bhatti, S., Khalil, W., Gul, S., Sajid, M.B., 2018. Design of an 87 kW Photovoltaic System for a University Building to Support LEED Certification. Paper presented at the 1st International Conference on High Performance Energy Efficient Buildings and Homes (HPEEBH 2018), Lahore, Pakistan.
3. Bhatti, S., Khalil, W., **Akbar, R.**, Sajid, M.B., 2018. Energy Consumption in Residential Sector of Pakistan. Paper presented at the 1st International Conference on High Performance Energy Efficient Buildings and Homes (HPEEBH 2018), Lahore, Pakistan.
4. S., Gul, Khalil, W., Bhatti, S., **Akbar, R.**, Sajid, M.B., 2018. Energy Consumption Profile of a K-12 School Building and Identification of Energy Conservation and Energy Efficiency Measures. Paper presented at the 1st International Conference on High Performance Energy Efficient Buildings and Homes (HPEEBH 2018), Lahore, Pakistan.

Chapter 1: Introduction

1.1 Energy Sector of Pakistan

The current electricity generation mix of Pakistan is highly skewed towards thermal powerplants, mostly operated on imported fuel oil. In addition to the carbon emissions, such dependence imposes a huge burden on country's economy and makes our electricity sector vulnerable to the fluctuations in international oil market prices. To overcome the supply-demand gap, the use of indigenous energy sources should be encouraged with a special focus on renewable energy deployment. This will lead to enhanced energy security of the country.

1.2 Sustainability in Higher Education Institutes

Universities can be thought of as small cities due to the huge amount of energy they consume and resulting environmental impact [1]. Velazquez et al. [2] defined a sustainable university as "a higher educational institution, as a whole or as a part, that addresses, involves and promotes, on a regional or a global level, the minimization of negative environmental, economic, societal, and health effects generated in the use of their resources in order to fulfill its functions of teaching, research, outreach and partnership, and stewardship in ways to help society make the transition to sustainable lifestyles". A sustainable campus community as defined by Cole [3] is "the one that acts upon its local and global responsibilities to protect and enhance the health and well-being of humans and ecosystems. It actively engages the knowledge of the university community to address the ecological and social challenges that we face now, and in the future".

Measuring, assessing and reporting of sustainability performance by organizations is a very important aspect which opens the way for continuous improvement. Sharing experiences, lessons learnt and best practices with peer institutions can help them achieve their sustainability goals. In an effort to reduce the environmental impact of their activities, businesses and other organizations all over the world have been using systems e.g., EU Eco-Management and Audit Scheme (EMAS), ISO-14001 Standard and Global Reporting Initiative (GRI) Standards to evaluate, report and improve their sustainability performance. But these systems are not specifically designed to be used for universities[1], [4]. Association for the Advancement of Sustainability in Higher Education (AASHE) was established in 2005 in North America. Now AASHE is comprised of over 900 members across the world including educational institutions, businesses and nonprofit organizations. AASHE launched STARS in 2010 as a framework for universities and colleges to measure their sustainability performance and look for areas of improvement. AASHE members get a considerable discount on program fees while participating in STARS (450 USD per year for non-OECD countries). On the basis of points earned, STARS participants achieve a STARS Bronze, Silver, Gold or Platinum rating, or recognition as a STARS Reporter [5], [6]. The rating system is based on environmental, economic and social indicators which are divided into four main categories related to campus activities: Academics, Engagement, Operations, and Planning & Administration, with an optional fourth category, Innovation and Leadership. These categories along with the weightages assigned to them are listed in Table 1.

Table 1 STARS Credit categories and available points (Version 2.1) [7]

Category	**Available points**
ACADEMICS	
Curriculum	40
Research	18
ENGAGEMENT	
Campus Engagement	21
Public Engagement	20
OPERATIONS	

Air & Climate	11
Buildings	8
Energy	10
Food & Dining	8
Grounds	3-4
Purchasing	6
Transportation	7
Waste	10
Water	6-8
PLANNING & ADMINISTRATION	
Coordination & Planning	8
Diversity & Affordability	10
Investment & Finance	7
Wellbeing & Work	7
INNOVATION & LEADERSHIP	
Exemplary Practice	0.5 for each credit
Innovation	1 for each credit

1.2.1 Green buildings

Buildings account for about 40% of the total global energy consumption [8] and thus provide a huge opportunity for improvement through energy efficiency and conservation measures. Green and sustainable buildings is an actively progressing area and has seen a lot of development in the past few decades. The Office of the Federal Environmental Executive defines green building as "the practice of 1) increasing the efficiency with which buildings and their sites use energy, water, and materials, and 2) reducing building impacts on human health and the environment, through better siting, design, construction, operation, maintenance, and removal — the complete building life cycle [9]."

1.2.2 Energy Efficiency and Energy Conservation

Energy efficiency is described by International Energy Agency (IEA) as the "first-fuel" [10] and it should be considered before renewable energy deployment. The cost as well as environmental impact of saving energy is much less than generating energy. Universities should adopt measures to promote energy efficiency and conservation throughout the campus. These include use of energy efficient appliances and HVAC systems, retrofitting of existing buildings to minimize their energy consumption and use of daylight and passive cooling. Design and construction of new buildings should follow international green building practices. Green buildings enhance productivity, health and comfort of the inhabitants and have less operating costs than their conventional counterparts.

1.2.3 Renewable Energy

Higher education institutions are large consumers of electricity and spend a lot of money on energy costs each year. On-campus renewable energy deployment can generate clean electricity to meet the demands of the university and is increasingly becoming popular all over the world. Alongside geothermal and wind, solar power is being installed by many universities. Financed by the US Department of Energy's SunShot Initiative, National Renewable Energy Laboratory (NREL) is providing technical assistance to higher education institutions to deploy solar. From 2000 to 2017, installed capacity of solar projects in American institutions has increased significantly. About 400 universities and colleges have adopted solar with about 710 MW of installed capacity [11].

Detailed techno-economic analysis is necessary before the installation of renewable energy systems to aid in decision making. The first step in this regard is the resource assessment of the campus using long term weather data to get an idea of the generation potential of different renewable energy systems e.g. solar and wind. Electrical load data is also required to determine electricity requirements of the campus. A number of software tools are available to model system performance e.g. PVsyst, PV*SOL, SAM (System Advisor Model) and HOMER (Hybrid Optimization of Multiple Energy Resources) which can estimate energy output of the proposed system. NREL also offers analysis services using its REopt model to help universities identify cost-effective measures to meet carbon reduction and energy performance goals by employing renewables [12]. Financial analysis is also performed to check if the project is economically viable.

Availability of space on rooftops, marginal lands and parking sheds in university campuses makes them good candidates for hosting renewable energy projects [13]. Solar PV systems are very common in university campuses and are preferred over other renewable energy systems owing to their modularity, scalability and ease of operation. Unlike wind turbines, a solar PV system can be installed at flexible locations and it is increasingly becoming cost-competitive. Eliminating the use of fossil fuel-based electricity can reduce greenhouse gas emissions produced as a result of campus activities and also bring enormous economic benefit to the university. Renewable energy systems can provide savings of over 5% for the first year and net present value (NPV) savings of 10-20% or more during the lifetime of the project. Visibility of such projects brings additional benefits for higher education institutions like student attraction, reputation enhancement, joint research projects etc. [14].

1.3 Scope of the work

This work analyzes the sustainability performance of National University of Sciences and Technology (NUST). The main focus of this study is the minimization of carbon footprint of academic buildings through

- i) Energy conservation
- ii) Energy efficiency
- iii) Renewable energy

Summary

This chapter introduces some of the key subjects in the thesis. The energy sector of Pakistan is briefly discussed to shed light on the motivation of this study. The subsequent section explains energy management in educational institutes and why it is important. Following this, green buildings, energy efficiency and conservation and renewable energy deployment is discussed.

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Chapter 2: Literature Review

2.1 Net Zero Energy Buildings (NZEB)

A net zero energy building produces as much energy as it consumes over a course of one year. This energy can be produced by any renewable energy source such as solar PV. Many definitions of NZEB exist in literature which can be found in [1], [2] and [3]. Four main categories of NZEB are listed as follows.

1. Net-Zero Site Energy
2. Net-Zero Source Energy
3. Net-Zero Energy Costs
4. Net-Zero Energy Emissions

2.2 Energy Consumption of a Building

The energy consumption of a building depends on various factors as explained below.

2.2.1 Building design

Design of a building dictates how it is going to respond to external environmental factors throughout the course of its life. Usually the buildings are constructed without considering the most favorable building orientation. This affects the solar heat gains and hence the heating and cooling loads. The materials used for building construction, type of fenestration, insulation of walls and roof and ventilation strategies determine the use of energy for thermal comfort of occupants.

2.2.2 Building systems

Energy efficient appliances should be installed wherever possible in a building. These appliances usually have a long life and when properly maintained, will pay back quickly for the additional cost incurred. A building's energy use can be divided into the following major categories.

1. Heating, Ventilation and Air Condition (HVAC) system
2. Lighting
3. Fans
4. Miscellaneous equipment, plug loads
5. Hot water system

2.2.3 User behavior

Occupants' behavior has a significant impact on the energy performance of buildings. This includes occupants' active and passive energy behaviors such as window or door opening, use of solar shades and louvres, adjusting HVAC setpoints, hot water usage, etc. A sound understanding of how the occupants use a building provides a pathway to improve the building's energy efficiency by changing occupant behavior.

2.3 Energy Audits

An energy audit follows a methodical approach to decision-making in the area of energy management. The primary objectives of an energy audit are as follows:

- To establish an energy consumption baseline
- To benchmark with similar facilities
- To identify energy management opportunities

According to ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) standards there are three types of audits, as discussed below [4].

2.3.1 Level – I audit

The Level 1 audit, also called a walk-through audit, is the most fundamental type of energy assessment. The audit begins with a detailed analysis of the energy bills for the previous 12 to 36 months to assess buildings energy efficiency and cost. A brief survey of the facility is conducted to identify areas of improvement. Low-cost and no-cost energy efficiency measures are suggested and potential capital-intensive modifications are also identified.

2.3.2 Level – II audit

A Level 2 audit involves a more detailed building survey and energy analysis. An energy consumption is breakdown is developed to identify major loads and areas that present the greatest energy savings potential. A Level 2 energy analysis also provides the savings and cost estimates of all possible energy efficiency measures for a building that meet client's constraints.

2.3.3 Level – III audit

Level 3 audit focuses on potential capital-intensive improvements identified during a Level 2 analysis. It requires more detailed data collection along with exhaustive engineering and economic analyses, often including computer simulation of the energy performance of the building. The rigorous data analysis is used to accurately predict energy and cost savings to minimize investment risk.

2.4 Previous Studies

Addressing the impacts of climate change requires universities to reduce their carbon footprint. University campuses consume large amounts of electricity which mostly comes from fossil fuels. Electricity consumption can be reduced by adopting energy efficiency and conservation measures. Along with this, universities are aiming to meet their energy demand through renewable energy sources [5]. Voluntary use of green power in higher education institutes in the US has increased rapidly from 2006 to 2014, with a 30-fold increase from 100,000 MWh to 3.06 million MWh [6]. Universities that use clean energy can help in achieving the target of the Paris Climate Agreement i.e. limiting global mean temperature rise below 2 degrees Celsius over pre-industrial levels.

Green university efforts have been initiated around the world. Environmental management systems (EMS) have been implemented in several European universities with the aim to reduce their environmental impact and track sustainability performance [7]. Saadatian et al. [8] carried out a study to observe sustainability practices in four Malaysian research universities and identified major shortcomings which should be overcome to catchup with the developed countries. Chinese universities are also actively engaged in adopting green initiatives which include environment friendly practices, cost effective measures for campus maintenance and raising public awareness [9]. China Green University Network (CGUN) was established in March 2011 to advance green campus development in China and promote collaborative research in the field of green education and sustainability [10]. Campus sustainability in India is in its initial stages, however this concept is gaining popularity which will lead to further adoption of sustainable practices in higher educational institutions [11].

Table 2 summarizes the key findings of few papers that are most relevant to this study.

Table 2 Literature Review

	Author and Year	**Title**	**Key Findings**
1	Rahman et al. (2010) [12]	“Energy conservation measures in an institutional building in sub-tropical climate in Australia”	Various energy conservation measures (ECMs) are investigated for a four-storied institutional building in hot and humid climate • With zero investment measures applied to the existing buildings, about 2.99% of energy can be saved annually. • All minor investment measures save around 12.02% of electrical energy annually. • With major investment, nearly 26.86% of electrical energy can be saved annually.
2	Sait (2013) [13]	“Auditing and analysis of energy consumption of an educational building in hot and humid area”	Detailed auditing was conducted of the building and recommendations were suggested related to the HVAC system, lighting and building envelope. • The cost analysis for the suggested modifications estimates energy savings of up to 45% and a payback period of 2.7 years.
3	Faghihi et al. (2015) [14]	“Sustainable campus improvement program design using energy efficiency and conservation”	This paper developed a system dynamics model of energy-based sustainability improvement programs to assess the impact of energy efficiency and conservation on energy and monetary savings.

4	Lee et al. (2016) [15]	"Economic feasibility of campus-wide photovoltaic systems in New England"	This study aims to assess the economic feasibility of the solar PV systems by analyzing actual data from the solar array on campus. The average payback period of a campus-wide PV system was calculated to be 11 years and was estimated to reduce overall building operating expenses by $250,000 or 8%.
5	Khoshbakht et al. (2018) [16]	"Energy use characteristics and benchmarking for higher education buildings"	This study investigates energy use characteristics of different types of higher education buildings and established an energy benchmark system. Research buildings had highest energy benchmark values (216 kWh/m^2/year), while the academic office buildings had lowest energy benchmark values (137 kWh/m^2/year).

Summary

This chapter discusses the literature survey done by the author. The concept of net zero energy buildings is explained. Following this, the key factors affecting energy consumption of a building are discussed. These include building design, building systems and user behavior. Three types of audits as defined by ASHRAE standards are discussed along with the data required and the expected outcomes. A brief review of previous studies conducted by higher educational institutions around the world is also provided.

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Chapter 3: Methodology

3.1 Campus Sustainability Assessment

Sustainability covers many operational aspects of a university such as minimizing the use of energy and water, reducing solid waste, incorporating it research and curriculum and most importantly, implementing effective policies to achieve this goal in all the aforementioned areas. Figure 1 shows the campus sustainability framework developed for this study. The focus of this thesis is energy efficiency and renewable energy of academic buildings. Separate proposals were submitted for water use efficiency in buildings and waste reduction in cafeterias which are not covered in this thesis. A course on energy management was developed which can be offered as a semester long course in graduate programs.

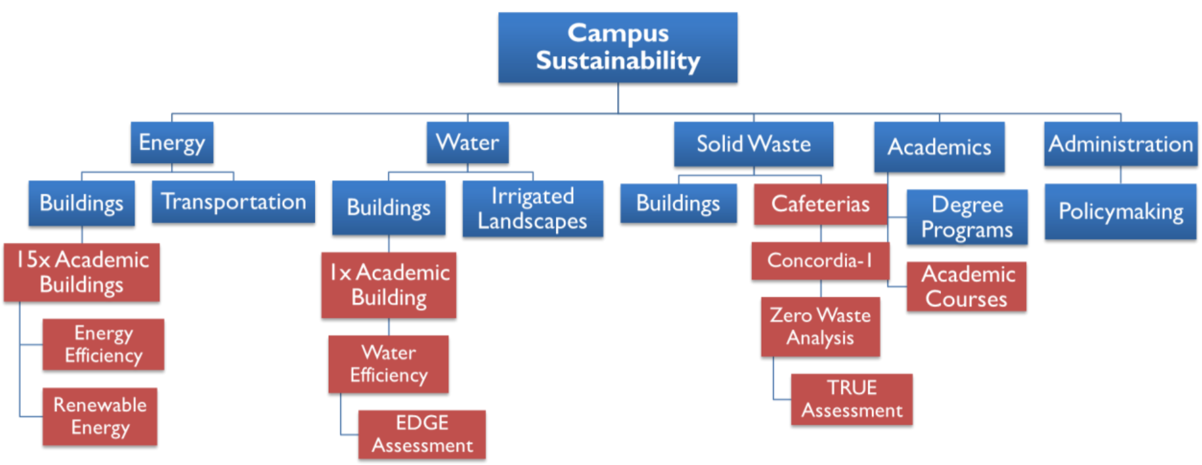

Figure 1 Campus sustainability assessment framework

3.2 Energy Efficiency of Academic Buildings

Figure 2 shows the steps followed for energy assessment of academic buildings in NUST. All the steps are briefed in the subsequent subsections.

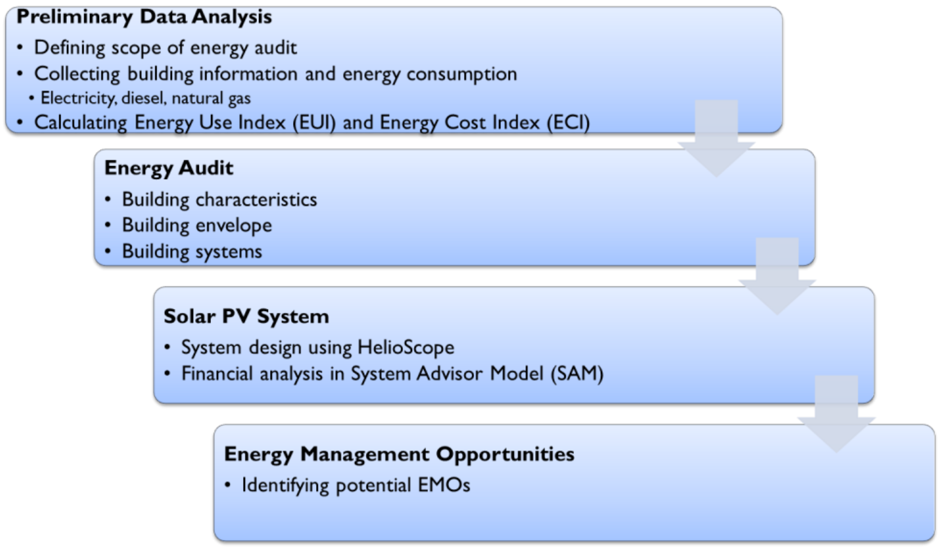

Figure 2 Energy assessment of academic buildings

3.2.1 Location and climate

Location and climate also affects the energy consumption of a building. National University of Sciences and Technology (NUST) is located in Islamabad (33.68° N, 73.05° E) which has a humid subtropical climate characterized by long and hot summers, a monsoon season and a short winter season. Table 3 shows the heating and cooling degree days for Islamabad [1] with a base temperature of 18°C. It shows that the cooling season is longer than the heating season, suggesting that buildings in the region should preferably be designed to reduce the cooling load.

Table 3 Heating and cooling degree days for Islamabad

Month	Average Temp (°C)	HDD	CDD
January	10.1	244.9	0

February	12.1	165.2	0
March	16.9	34.1	0
April	22.6	0	138
May	27.5	0	294.5
June	31.2	0	396
July	29.7	0	362.7
August	28.5	0	325.5
September	27	0	270
October	22.4	0	136.4
November	16.5	45	0
December	11.6	198.4	0

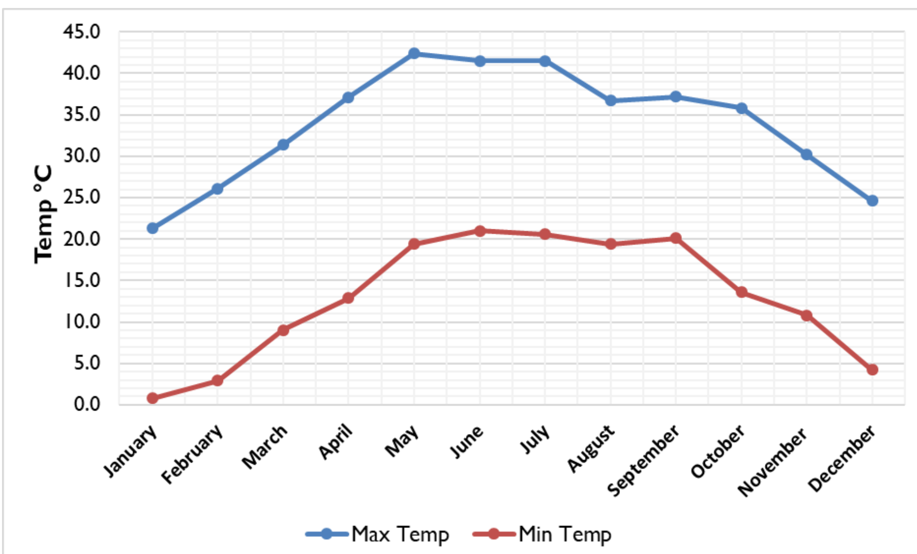

Figure 3 Maximum and minimum monthly temperatures in Islamabad

3.2.2 Data Collection

The data required to perform walkthrough audits was collected from PMO office, NUST.

3.2.2.1 Building Drawings

Building areas, front elevations and electrical plans were obtained for all academic buildings in NUST. Floor plans were also obtained to determine space functions.

3.2.2.2 Building Energy Consumption

All academic buildings in NUST rely on three sources of energy; electricity, naturals gas and diesel fuel. Electricity and natural gas bills were collected for the year 2017. Liters of fuel consumed by the diesel generator that serves the building were also noted for the same year.

3.2.3 Walkthrough audits

Before conducting audit, a preliminary energy use analysis was carried out for each building in which the utility bills were analyzed and Energy Utilization Index (EUI) and Energy Cost Index (ECI) was calculated. After that the walkthrough audit was performed which included interviewing the operating personnel about building use and occupancy patterns, survey of major building systems and inspecting the building envelope. Sources of energy wastage in the building were noted and potential energy saving opportunities were identified. Pictures were taken during the audit for future reference.

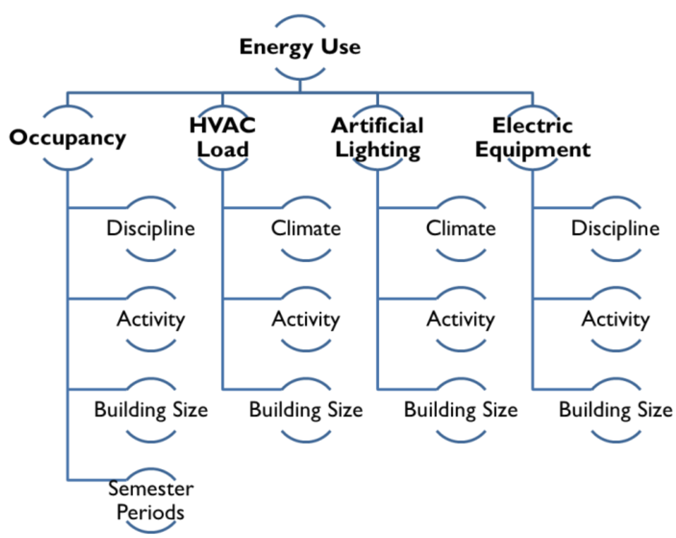

Figure 4 Energy use in a university building [2]

3.3 Solar PV System Design

3.3.1 HelioScope

Numerous software tools are available for the design and performance analysis of solar PV systems for buildings. Performing such an analysis requires ground measured or satellite-based weather data, electrical consumption of the building and estimation of different loss factors associated with a PV system. Energy yield of a PV system is influenced by many factors including solar irradiance, temperature, soiling, degradation of its components and mismatch loss. A major loss in PV system output is shading from surrounding trees and objects. Therefore, it must be calculated as accurately as possible to get a true picture of the system output. This study makes use of HelioScope [3] which is web-based software for solar PV system design. Building rooftop and parking lot are considered for the installation of PV modules.

3.3.2 System Advisor Model (SAM)

The System Advisor Model [4] is an opensource software developed by the National Renewable Energy Laboratory (NREL) for predicting the performance and financial feasibility of residential, commercial, and utility-scale renewable energy projects. Based on the project’s location, design parameters, equipment and installation cost, SAM calculates financial metrics such as net present value, payback period and levelized cost of electricity (LCOE) for a project.

Summary

This chapter details the methodology adopted for this research work. Firstly the campus sustainability framework developed for this study is discussed. The focus area is identified as energy efficiency and renewable energy potential of academic buildings. Location and climate of the buildings is discussed briefly. Then the process of data collection is explained which includes building drawings and utility bills. Observations made during the walkthrough audits are also mentioned. In the end the software programs used for the technoeconomic analysis of solar PV systems are described.

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[2] M. Khoshbakht, Z. Gou, and K. Dupre, "Energy use characteristics and benchmarking for higher education buildings," *Energy Build.*, vol. 164, pp. 61–76, 2018.

[3] "HelioScope: Advanced Solar Design Software." [Online]. Available: https://www.helioscope.com/. [Accessed: 02-Mar-2019].

[4] "System Advisor Model (SAM) | National Renewable Energy Laboratory." [Online]. Available: https://sam.nrel.gov/. [Accessed: 02-Mar-2019].

Chapter 4: Audit Results

4.1 School of Electrical Engineering and Computer Science (SEECS)

4.1.1 Building Specifications

SEECS is the largest school of NUST by enrollment and it was completed in 2008. SEECS has three buildings; undergraduate, postgraduate and faculty block. The main façade of all the three blocks faces northeast. The UG block has 2two floors above grade while the PG and faculty block has 3 floors above grade. PG block also has a basement. SEECS has 15 classrooms, 32 laboratories, individual and shared office space, a seminar hall and a library. A data center is also located in PG block.

The walls are composed of bricks and have no insulation. The roof is insulated with damp/partially heat proof material. All windows are single glazed and have aluminum frames. Some of the windows are shaded as shown in the Figure 2. Windows in classrooms and offices have blinds installed to provide shading. Some of the windows are operable.

Figure 5 Window employing horizontal and vertical shading

4.1.2 Building Systems

SEECS is served by a direct fired absorption chiller having a capacity of 1050 tons. It also has split ACs installed in offices and few labs. The lighting system has LEDs and Fluorescent tube lights and lamps. All the lights are controlled manually.

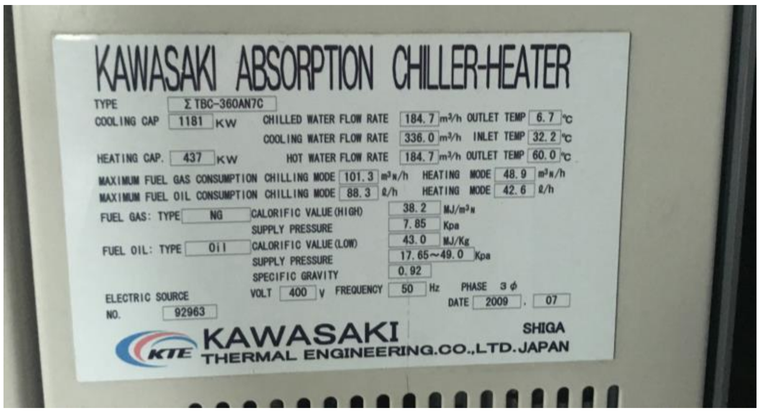

Figure 6 Nameplate of Kawasaki Absorption Chiller

4.1.3 Building Energy Consumption

SEECS has the highest energy consumption among all the academic buildings of NUST. Its monthly electricity, natural gas and diesel consumption along with costs are provided in the figures below. SEECS also has three diesel generators which are used as a backup power supply. EUI and ECI of SEECS building are calculated to be 747.9 kWh/m^2/year and 1663.2 PKR/m^2/year respectively.

Table 4 Diesel consumption of SEECS building

Gen Set Company	kVA Rating	kW Rating	Engine Make/Model	Fuel Consumed (liters)
Siemens DG Set	400	200	Doosan/P-158LE	2040
Siemens DG Set	250	200	Doosan/P-126LE	1020
Siemens DG Set	250	200	CUMMINS/QSL-9	440

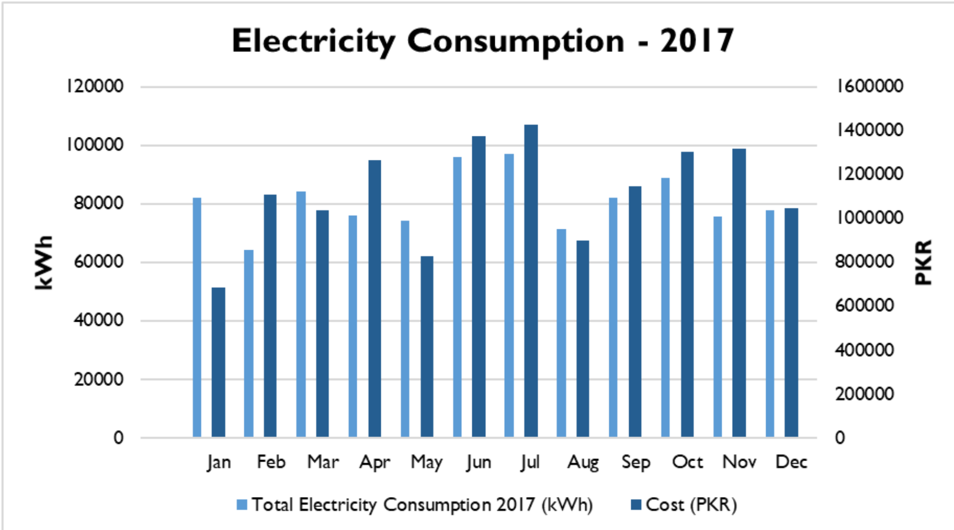

Figure 7 Monthly electricity consumption of SEECS – 2017

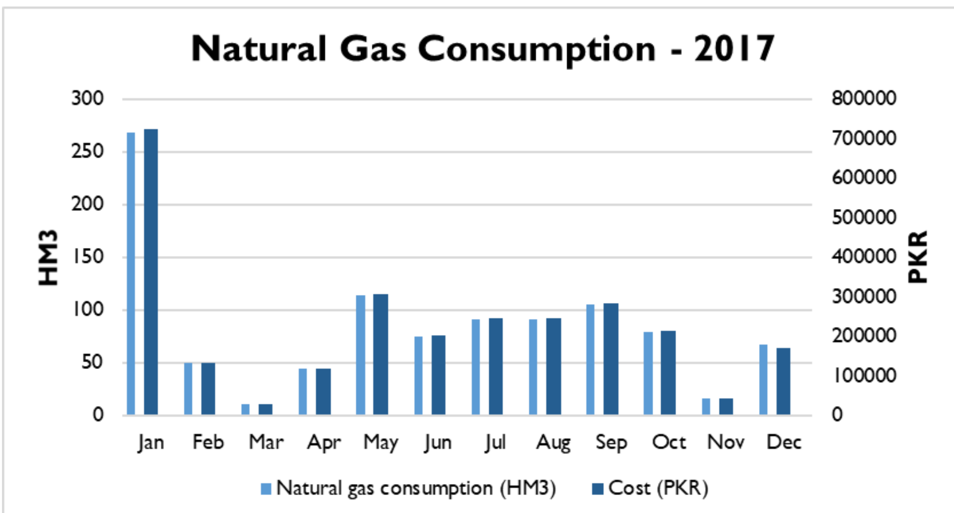

Figure 8 Monthly natural gas consumption of SEECS – 2017

4.1.4 Energy Management Opportunities

During the walkthrough audits, several issues were observed which need to be addressed.

1. Poor lighting in corridors
2. Inefficient air conditioners
3. Damaged False Ceiling
4. Infiltration through glass doors
5. Heat gain through windows

Figure 9 Glass door with gaps

4.2 School of Chemical and Materials Engineering (SCME)

4.2.1 Building Specifications

SCME building, completed in 2010, has three floors above grade. The main façade of the building faces south and it has a high window to wall ratio. SCME has 7 classrooms, 27 laboratories, individual and shared office space, a seminar hall and a library.

The walls are composed of bricks and have no insulation. The roof is insulated with damp/partially heat proof material. All windows are single glazed and have aluminum frames. Windows in classrooms and offices have blinds installed to provide shading. Some of the windows are operable.

Figure 10 Main facade of SCME building

4.2.2 Building Systems

SCME has split ACs installed to provide thermal comfort in labs, offices and classrooms. During building construction a centralized HVAC system was installed which did not function properly so it is no longer used. But the ducts and indoor units are not removed. The lighting system has LEDs and Fluorescent tube lights and lamps. All the lights are controlled manually.

Figure 11 Inside a classroom in SCME

4.2.3 Building Energy Consumption

Monthly electricity and natural gas consumption of SCME building along with the costs are provided in the figure below. SCME also has one diesel generator which is used as a backup power supply. EUI and ECI of SCME building are calculated to be 195.2 kWh/m^2/year and 634 PKR/m^2/year respectively.

Table 5 Diesel consumption of SCME building

Gen Set Company	kVA Rating	kW Rating	Engine Make/Model	Fuel Consumed (liters)
Siemens DG Set	250	200	VOLVO/TAD734 GE	1080

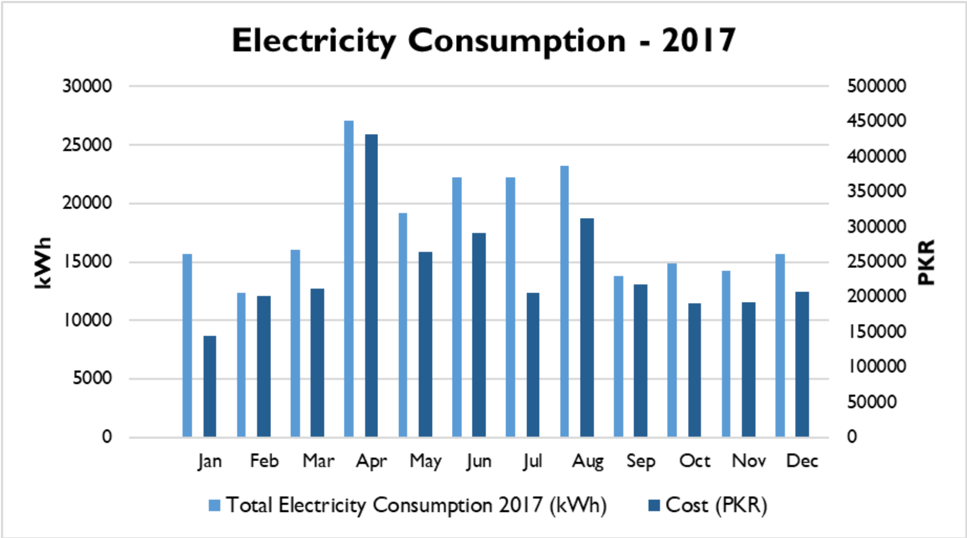

Figure 12 Monthly electricity consumption of SCME - 2017

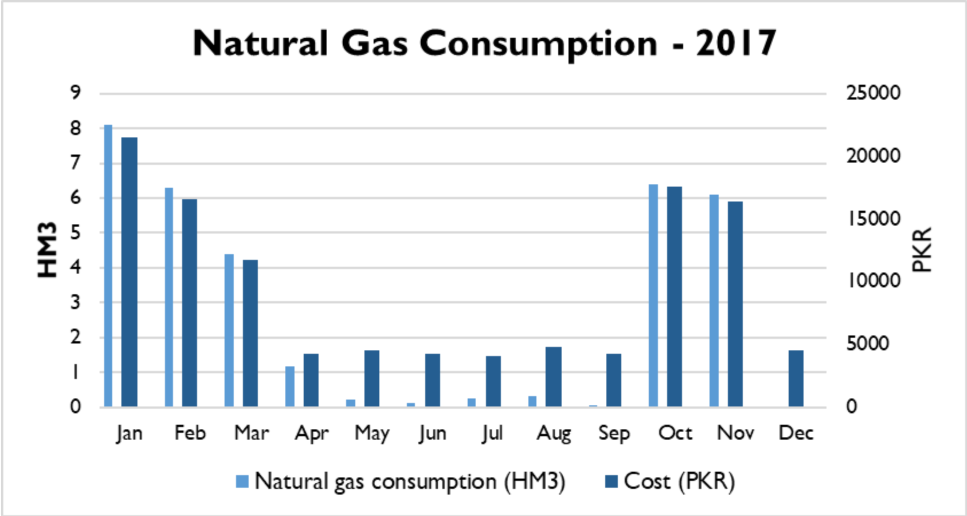

Figure 13 Monthly natural gas consumption of SCME - 2017

4.2.4 Energy Management Opportunities

During the walkthrough audits, several issues were observed which need to be addressed.

1. No exhaust system in laboratories dealing with chemicals
2. Inefficient air conditioners
3. Nonfunctional HVAC system
4. Damaged false ceiling
5. Infiltration through doors

6. Heat gain through windows

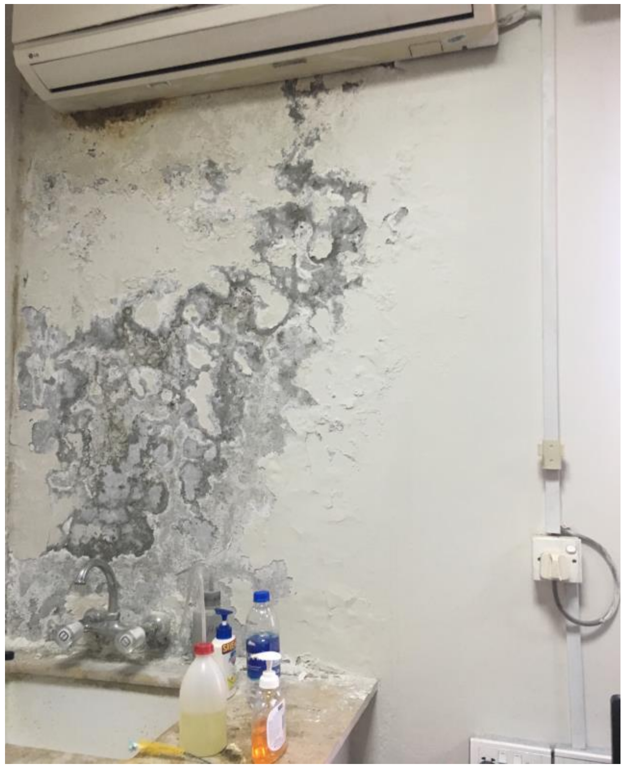

Figure 14 Damp internal wall of a lab in SCME

4.3 School of Social Sciences and Humanities (S3H)

4.3.1 Building Specifications

S3H is a new building and it was completed in 2013. It has four floors above grade and the main façade of the building faces northeast. S3H has 11 classrooms, 5 laboratories, individual and shared office space and two studios.

The walls are composed of bricks and have no insulation. The roof is insulated with damp proof material. All windows are single glazed and have aluminum frames. Windows in classrooms and offices have blinds installed to provide shading. Some of the windows are operable.

Figure 15 Main facade of S3H building

4.3.2 Building Systems

S3H building is served by a combination of split ACs and a compression-based chiller having a capacity of 414 tons to provide thermal comfort in labs, offices and classrooms. The lighting system has LEDs and Fluorescent tube lights and lamps. All the lights are controlled manually.

Figure 16 Nameplate of an outdoor unit installed on S3H rooftop

4.3.3 Building Energy Consumption

Monthly electricity and diesel consumption of S3H building along with the costs are provided in the figure below. S3H also has one diesel generator which is used as a backup power supply. S3H building does not have a natural gas connection. EUI and ECI of S3H building are calculated to be 210.8 kWh/m^2/year and 806.2 PKR/m^2/year respectively.

Table 6 Diesel consumption of S3H building

Gen Set Company	kVA Rating	kW Rating	Engine Make/Model	Fuel Consumed (liters)
Orient DG Set	250	200	CUMMINS/QSL-9	700

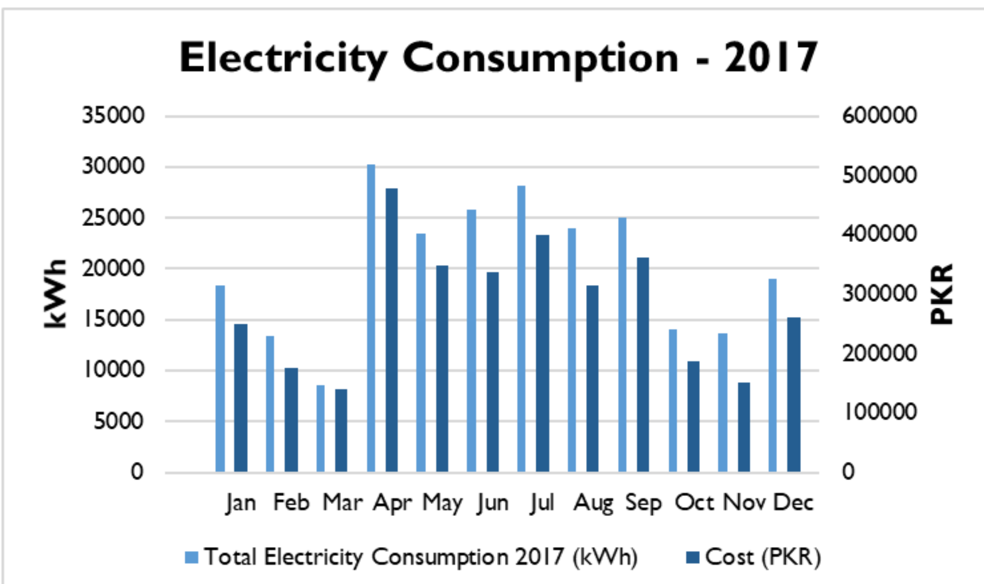

Figure 17 Monthly electricity consumption of S3H - 2017

4.3.4 Energy Management Opportunities

During the walkthrough audits, several issues were observed which need to be addressed.

1. Inefficient air conditioners

2. Infiltration through doors
3. Heat gain through windows

Figure 18 An example of infiltration through doors in S3H building

4.4 Atta-Ur-Rahman School of Applied Biosciences (ASAB)

4.4.1 Building Specifications

ASAB building, completed in 2010, has three floors above grade. The main façade of the building faces northeast and it has a moderate window to wall ratio. ASAB has 6 classrooms, 22 laboratories, individual and shared office space, a seminar hall and a library.

The walls are composed of bricks and have no insulation. The roof is insulated with damp proof material. All windows are single glazed and have aluminum frames. Windows in classrooms and offices have blinds installed to provide shading. Some of the windows are operable.

Figure 19 Main facade of ASAB building

4.4.2 Building Systems

ASAB has split ACs installed to provide thermal comfort in labs, offices and classrooms. The lighting system has LEDs and Fluorescent tube lights and lamps. All the lights are controlled manually. The building also has a data center with an AC which operates continuously.

Figure 20 Shared office space in ASAB

4.4.3 Building Energy Consumption

Monthly electricity and natural gas consumption of ASAB building along with the costs are provided in the figure below. ASAB also has one diesel generator which is used as a backup power supply. EUI and ECI of ASAB building are calculated to be 179.1 kWh/m^2/year and 585 PKR/m^2/year respectively.

Table 7 Diesel consumption of ASAB building

Gen Set Company	kVA Rating	kW Rating	Engine Make/Model	Fuel Consumed (liters)
Siemens DG Set	250	200	CUMMINS/QSL-9	1040

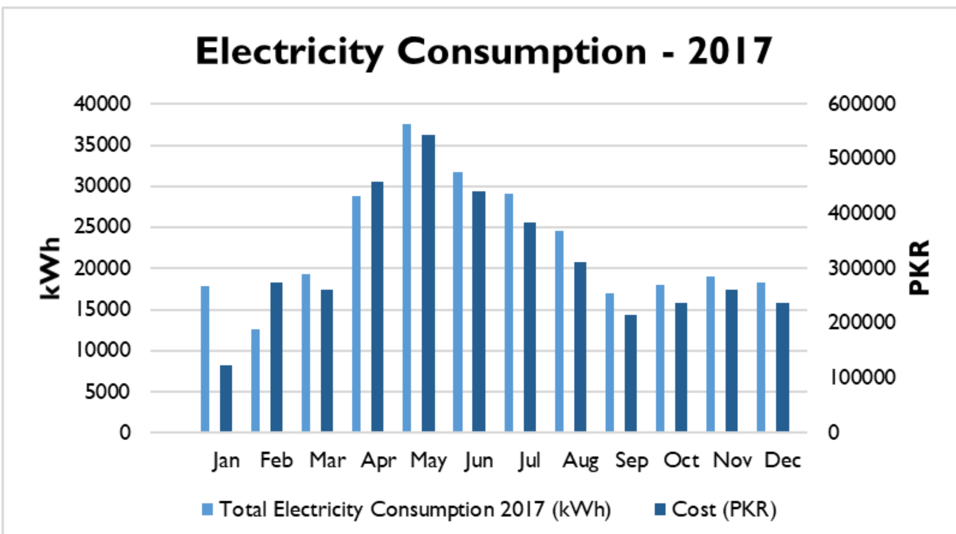

Figure 21 Monthly electricity consumption of ASAB - 2017

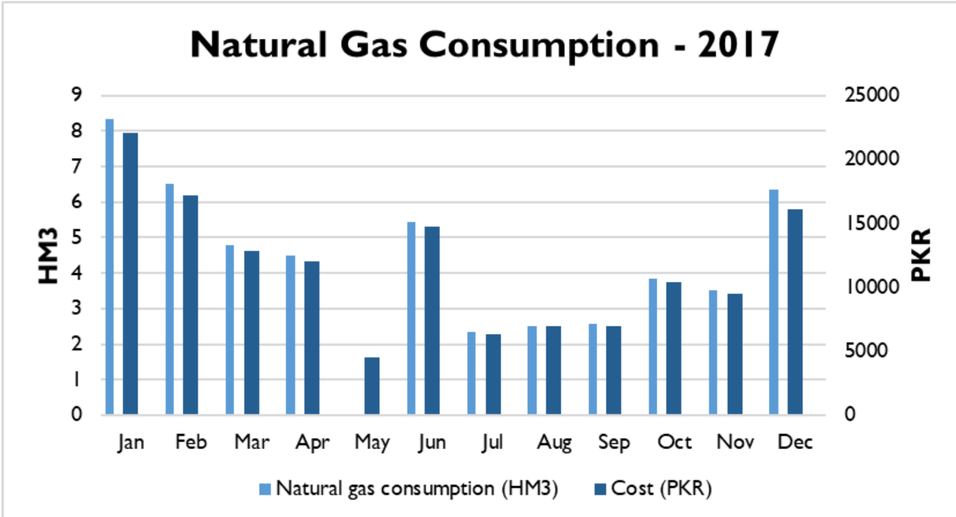

Figure 22 Monthly natural gas consumption of ASAB - 2017

4.4.4 Energy Management Opportunities

During the walkthrough audits, several issues were observed which need to be addressed.

1. Inefficient air conditioners
2. Infiltration through doors
3. Heat gain through windows

Figure 23 An example of infiltration through doors in ASAB building

4.5 NUST Institute of Civil Engineering (NICE)

4.5.1 Building Specifications

NICE building was completed in 2010 and it has two floors above grade. The main façade of the building faces northeast and it has a moderate window to wall ratio. NICE has 9 classrooms, 5 laboratories, individual and shared office space and a drawing hall.

The walls are composed of bricks and have no insulation. The roof is made of CGI sheet due to which it is very hot on the first floor in summers. All windows are single glazed and have aluminum frames. Windows in classrooms and offices have blinds installed to provide shading. Some of the windows are operable.

Figure 24 Main facade of NICE building

4.5.2 Building Systems

NICE has split ACs installed to provide thermal comfort in labs, offices and classrooms. The lighting system has LEDs and fluorescent tube lights and lamps. All the lights are controlled manually. Blower heaters are used in winters.

Figure 25 Inside a classroom in NICE

4.5.3 Building Energy Consumption

Monthly electricity and diesel consumption of NICE building along with the costs are provided in the figure below. NICE also has one diesel generator which is used as a backup power supply. NICE building does not have a natural gas connection. EUI and ECI of NICE building are calculated to be 82 kWh/m^2/year and 290.4 PKR/m^2/year respectively.

Table 8 Diesel consumption of NICE building

Gen Set Company	kVA Rating	kW Rating	Engine Make/Model	Fuel Consumed (liters)
Siemens DG Set	250	200	VOLVO/TAD740 GE	780

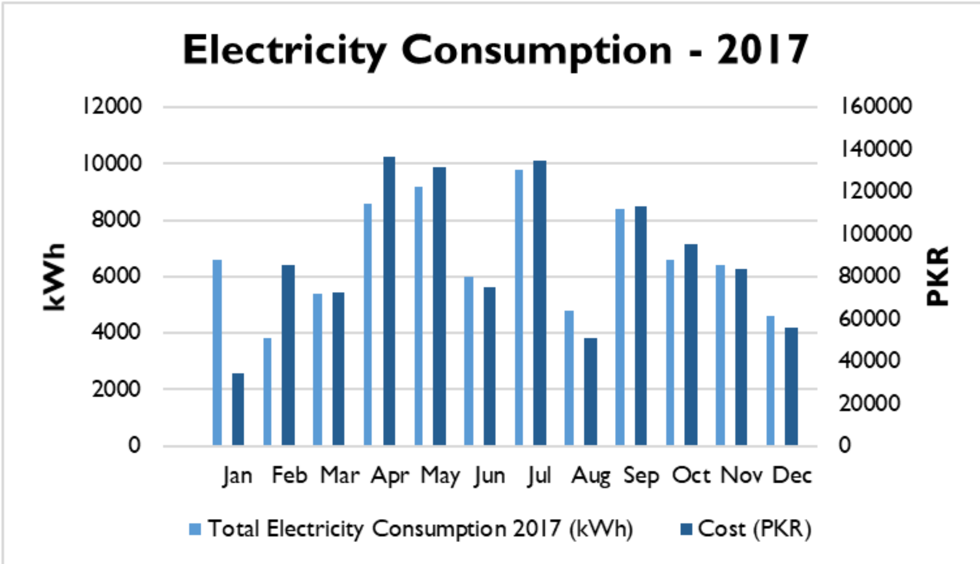

Figure 26 Monthly electricity consumption of NICE - 2017

4.5.4 Energy Management Opportunities

During the walkthrough audits, several issues were observed which need to be addressed.

1. Inefficient air conditioners
2. Infiltration through doors
3. Heat gain through windows
4. Damaged false ceiling

Summary

This chapter discusses the results of walkthrough audits of academic buildings. The general characteristics of the building envelope are described. Building systems such as HVAC, lighting are reviewed and energy consumption of the building is presented in the form of graphs. Major energy management opportunities noted during the audits are also discussed briefly.

Chapter 5: Solar Photovoltaic System Design

5.1 School of Electrical Engineering and Computer Science (SEECS)

5.1.1 System Specifications

Four PV systems with a cumulative capacity of 389 kW were designed for the rooftops of UG, PG and Faculty Block and the parking lot. System specifications for all the four systems are listed in the table below.

Table 9 PV system technical parameters (SEECS)

Weather File	TMY, 10 km grid (Meteonorm)
Module	YL315P-35b (Yingli)
Inverter	SB 5000TL (240 V) (SMA)
Azimuth	180°
Tilt	25°
Load Ratio	0.9 – 1.25

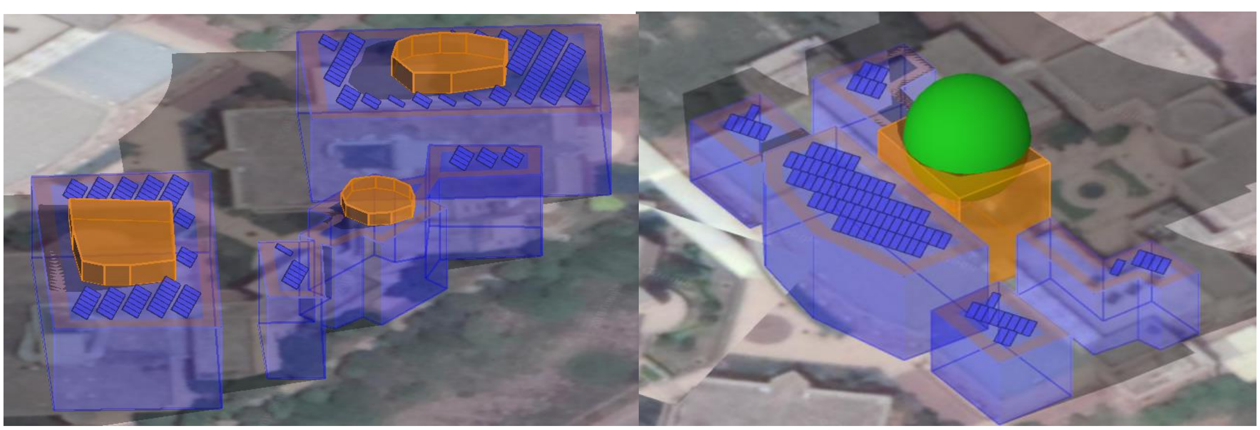

Figure 27 Solar PV system layout for SEECS UG block

5.1.2 System Output

Monthly energy generation of all the systems is given in Figure 27 and we can see that it follows the same trend as the consumption pattern. The capacity factor of the system comes out to be 16.1% while the performance ratio is 0.75. During hot summer months the electricity demand is high because of the cooling load. The PV system output during this time is also high due to high values of solar irradiance. The electricity consumption decreases as winter approaches. A battery bank was not considered for this system but if we have multiple sources of electricity like batteries, diesel generators, solar PV and grid electricity, then an intelligent dispatch strategy can be devised to minimize consumption of electricity from the grid and diesel generators.

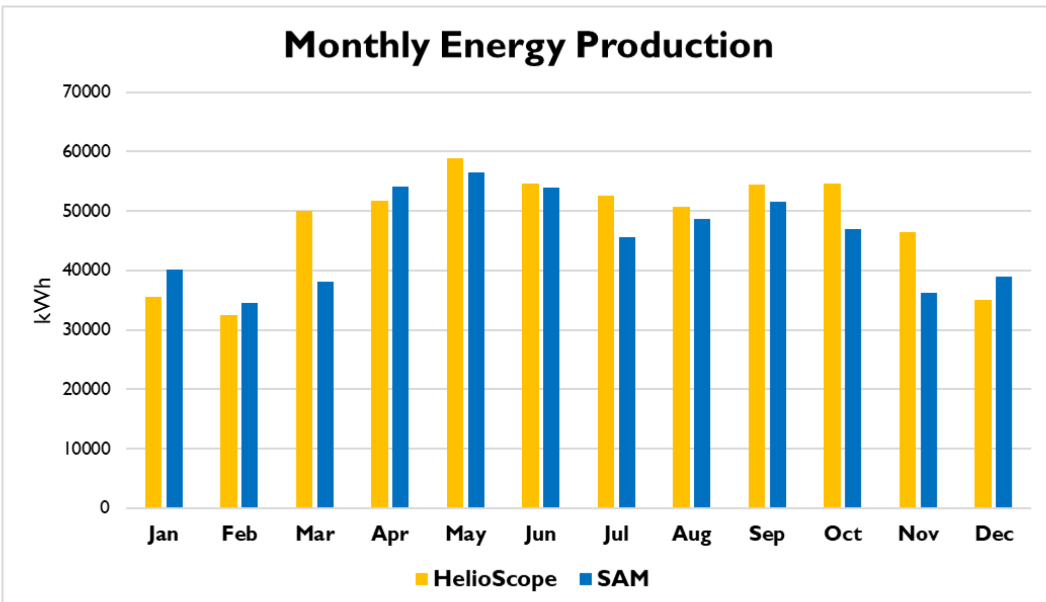

Figure 28 Monthly energy production of the system (SEECS)

5.1.3 Financial Analysis

Financial analysis of the PV system was performed in System Advisor Model (SAM) which predicts the performance of the system and estimates the cost of energy based on the weather data, operating costs and design parameters of the system. The following table shows results obtained for the system designed for SEECS.

Table 10 Financial metrics for solar PV system (SEECS)

Net Capital Cost	$634,053
Levelized Cost of Energy (LCOE)	14.96 ¢/kWh
Net Present Value (NPV)	$1,145,835
Payback Period	5.02 years

5.2 School of Chemical and Materials Engineering (SCME)

5.2.1 System Specifications

Three PV systems with a cumulative capacity of 242 kW were designed for the rooftop and the parking lot of SCME building. System specifications for all the three systems are listed in the table below.

Table 11 PV system technical parameters (SCME)

Weather File	TMY, 10 km grid (Meteonorm)
Module	YL315P-35b (Yingli)
Inverter	Sunny Tripower 20000 TL-US (SMA)
Azimuth	180°
Tilt	25°
Load Ratio	0.9 – 1.25

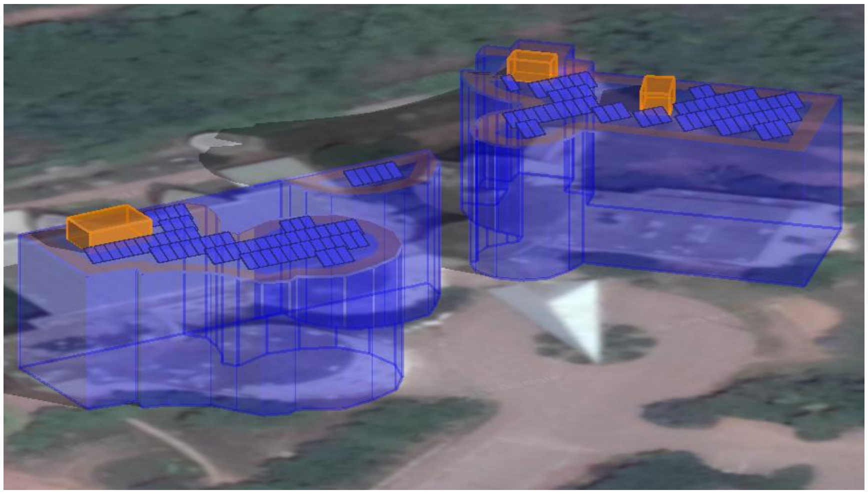

Figure 29 Solar PV system layout for SCME rooftop

5.2.2 System Output

Monthly energy generation of all the systems is given in the figure below and we can see that it follows the same trend as the consumption pattern. The capacity factor of the system comes out to be 15% while the performance ratio is 0.69. This is slightly low because the student parking lot is far from the main building and the output reduces due to wiring losses.

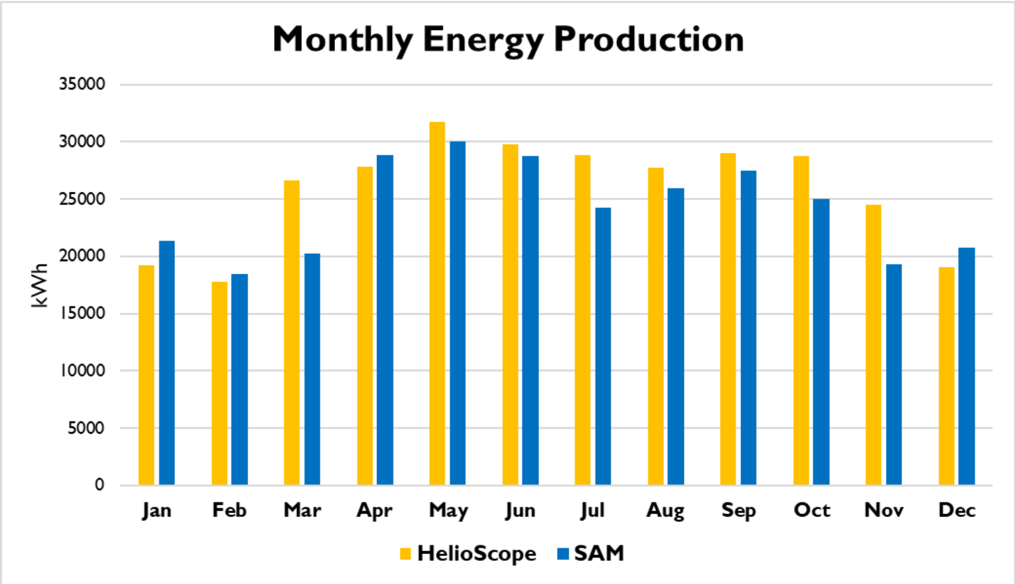

Figure 30 Monthly production of the system (SCME)

5.2.3 Financial Analysis

Financial analysis of the system was performed in System Advisor Model (SAM). The following table shows results obtained for the system designed for SCME.

Table 12 Financial metrics for solar PV system (SCME)

Net Capital Cost	\$402,641
Levelized Cost of Energy (LCOE)	17.46 ¢/kWh
Net Present Value (NPV)	\$529,419
Payback Period	6.07 years

5.3 School of Social Sciences and Humanities (S3H)

5.3.1 System Specifications

A single PV system was designed for S3H rooftop with a capacity of 11.3 kW. S3H has a shared parking lot with CIPS building. System specifications for the system are listed in the table below.

Table 13 PV system technical parameters (S3H)

Weather File	TMY, 10 km grid (Meteonorm)
Module	YL315P-35b (Yingli)
Inverter	Sunny Boy SB 11000TL (240 V) (SMA)
Azimuth	180°
Tilt	25°
Load Ratio	1.03

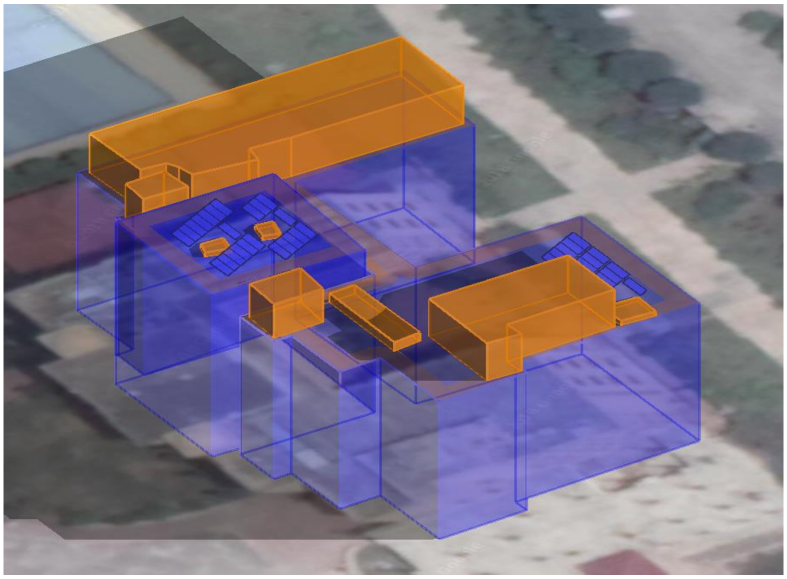

Figure 31 Solar PV system layout for S3H rooftop

5.3.2 System Output

Monthly energy generation of the system is given in the figure below and we can see that it follows the same trend as the consumption pattern. The capacity factor of the system comes out to be 15.9% while the performance ratio is 0.74.

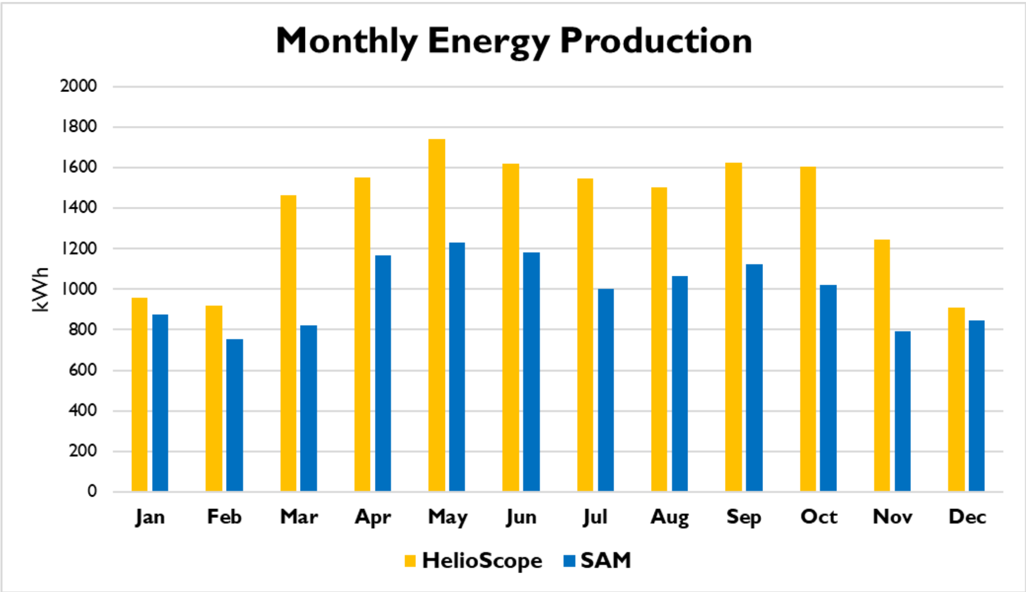

Figure 32 Monthly energy production of the system (S3H)

5.3.3 Financial Analysis

Financial analysis of the PV system designed for S3H was performed in System Advisor Model (SAM), results of which are provided in the following table.

Table 14 Financial metrics for solar PV system (S3H)

Net Capital Cost	$11,048
Levelized Cost of Energy (LCOE)	16.06 ¢/kWh
Net Present Value (NPV)	$24,286
Payback Period	5.1 years

5.4 Atta-Ur-Rahman School of Applied Biosciences (ASAB)

5.4.1 System Specifications

Two PV systems with a cumulative capacity of 237 kW was designed for the rooftop and parking lot of ASAB building. System specifications for both the systems are listed in the table below.

Table 15 PV system technical parameters (ASAB)

Weather File	TMY, 10 km grid (Meteonorm)
Module	YL315P-35b (Yingli)
Inverter	Sunny Tripower 20000 TL-US (SMA)
Azimuth	180°
Tilt	25°
Load Ratio	1.1

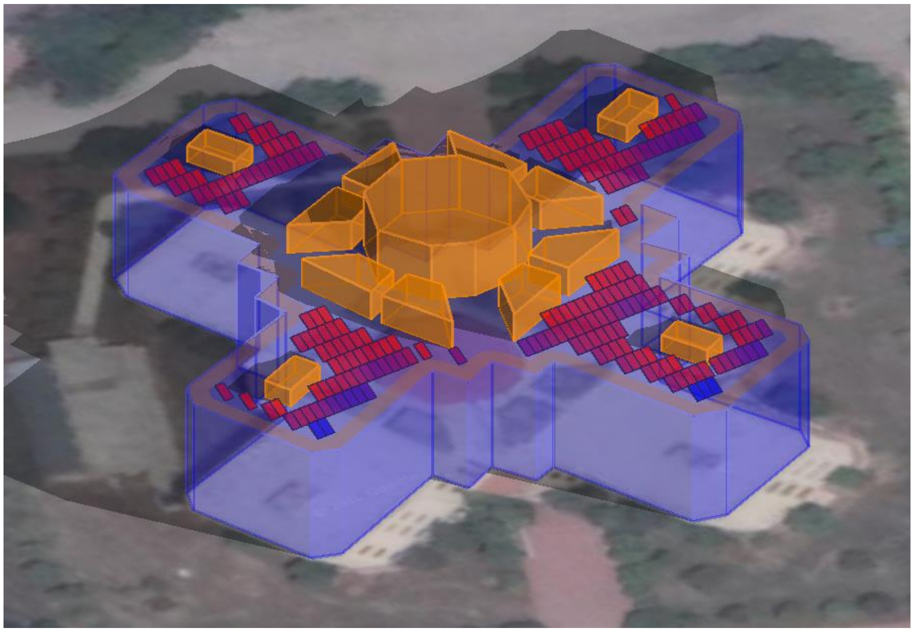

Figure 33 Solar PV system layout for ASAB rooftop

5.4.2 System Output

Monthly energy generation of all the systems is given in the figure below. The capacity factor of the system comes out to be 15.9% while the performance ratio is 0.74.

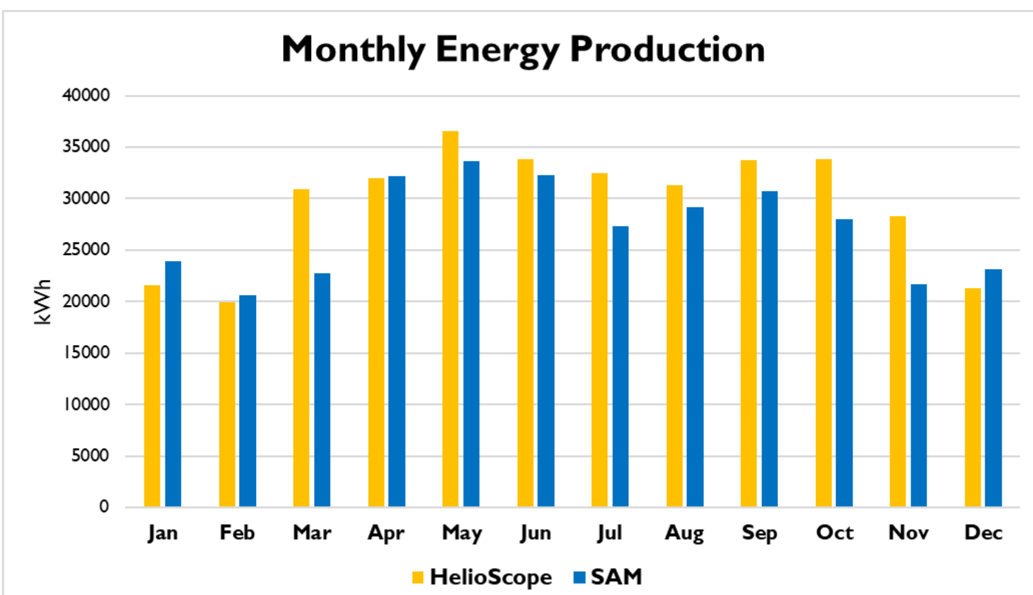

Figure 34 Monthly energy production of the system (ASAB)

5.4.3 Financial Analysis

Financial analysis of the system was performed in System Advisor Model (SAM). The following table shows results obtained for the system designed for ASAB.

Table 16 Financial metrics for solar PV system (ASAB)

Net Capital Cost	$383,377
Levelized Cost of Energy (LCOE)	15.32 ¢/kWh
Net Present Value (NPV)	$672,120
Payback Period	5.4 years

5.5 NUST Institute of Civil Engineering (NICE)

5.5.1 System Specifications

Two PV systems with a cumulative capacity of 206 kW was designed for the parking lot of NICE building. Since the roof is made of CGI sheet so it cannot support the weight of PV modules. System specifications for the system are listed in the table below.

Table 17 PV system technical parameters (NICE)

Weather File	**TMY, 10 km grid (Meteonorm)**
Module	YL315P-35b (Yingli)
Inverter	STP 12000TL-10 (SMA)
Azimuth	180°
Tilt	25°
Load Ratio	1.03

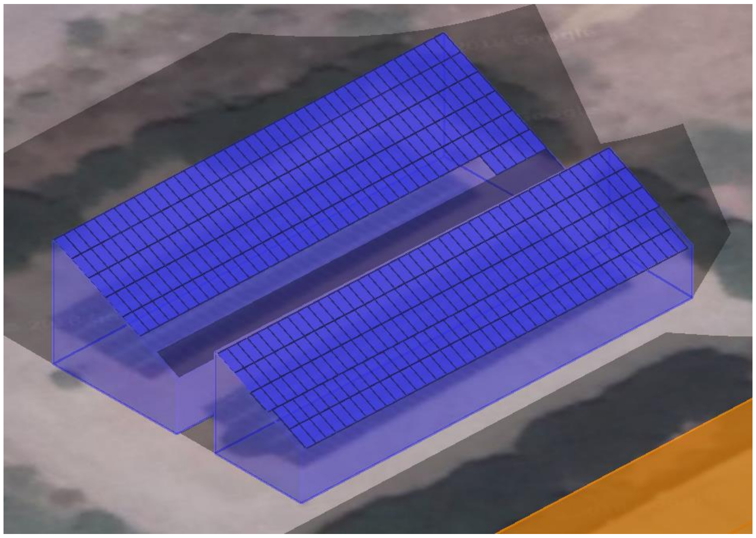

Figure 35 Solar PV system layout for NICE parking

5.5.2 System Output

Monthly energy generation of the system is given in the figure below. The capacity factor of the system comes out to be 16.7% while the performance ratio is 0.77.

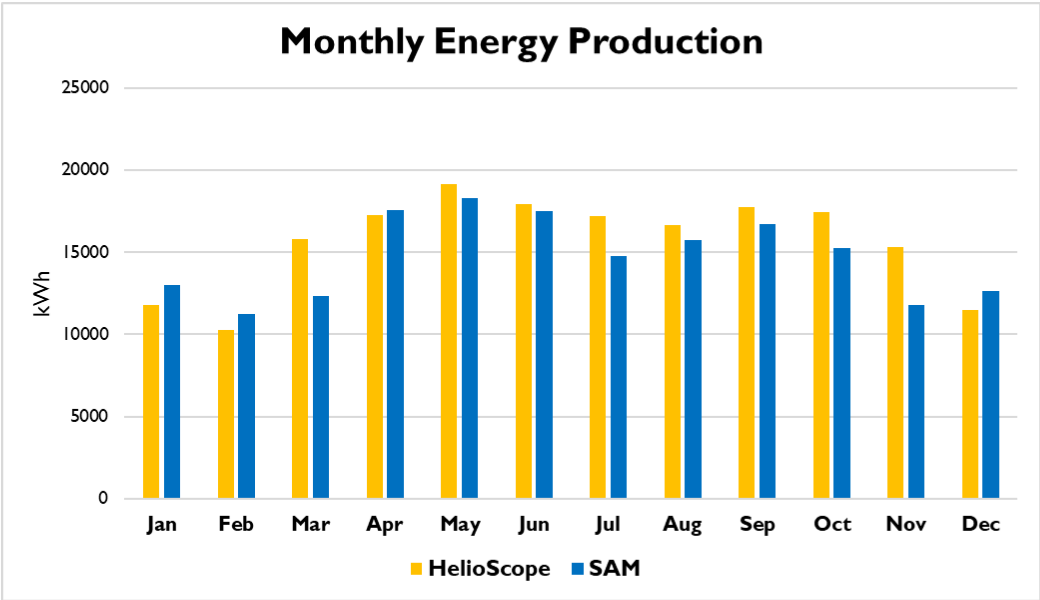

Figure 36 Monthly energy production of the system (NICE)

5.5.3 Financial Analysis

Financial analysis of the system was performed in System Advisor Model (SAM) which makes performance predictions and cost of energy estimates for the PV system based on installation and operating costs and system design parameters specified as inputs to the model. The following table shows results obtained for the system designed for NICE.

Table 18 Financial metrics for solar PV system (NICE)

Net Capital Cost	$217,562
Levelized Cost of Energy (LCOE)	15.89 ¢/kWh
Net Present Value (NPV)	$362,785
Payback Period	5.8 years

Summary

This chapter details the design and feasibility analysis that was conducted for the solar PV systems using HelioScope and SAM. This section of the study also discusses the parameters utilized for the feasibility study along with the financial metrics such as NPV, LCOE and payback calculations.

Chapter 6: Conclusions and Recommendations

6.1 Conclusions

A building's energy use is dictated by the local climate, type of building, building's design and specifications and behavioral patterns of occupants. Energy efficiency measures for a building should ideally be investigated at the design and construction stage, when they easier and relatively inexpensive to implement. But this does not exclude existing buildings from taking advantage of these measures. Retrofitting projects can lead to reduced energy consumption and operational costs.

As a part of this project ASHRAE level-I audits were conducted for academic buildings in NUST. It was observed that the buildings in NUST are not constructed according to green building practices which results in poor energy performance throughout the building's life. Most of the buildings have high window to wall ratios and no insulation in walls which increase the cooling load during summers. The windows are single glazed with aluminum frames which further adds to this problem. The HVAC system is poorly designed and offers a big opportunity for improvement, but the high cost associated with retrofitting of such a system is a constraint. Inefficient lights and fans if replaced with efficient ones can offer significant savings in energy costs.

Figure 37 shows the Energy Utilization Index (EUI) and Energy Cost Index (ECI) of all academic buildings in NUST. It shows that IGIS and SEECS have the highest EUI and ECI. This can be explained by the fact that SEECS has a large HVAC system that runs throughout the year. Also, SEECS and IGIS have datacenters that have precision cooling system running at all times.

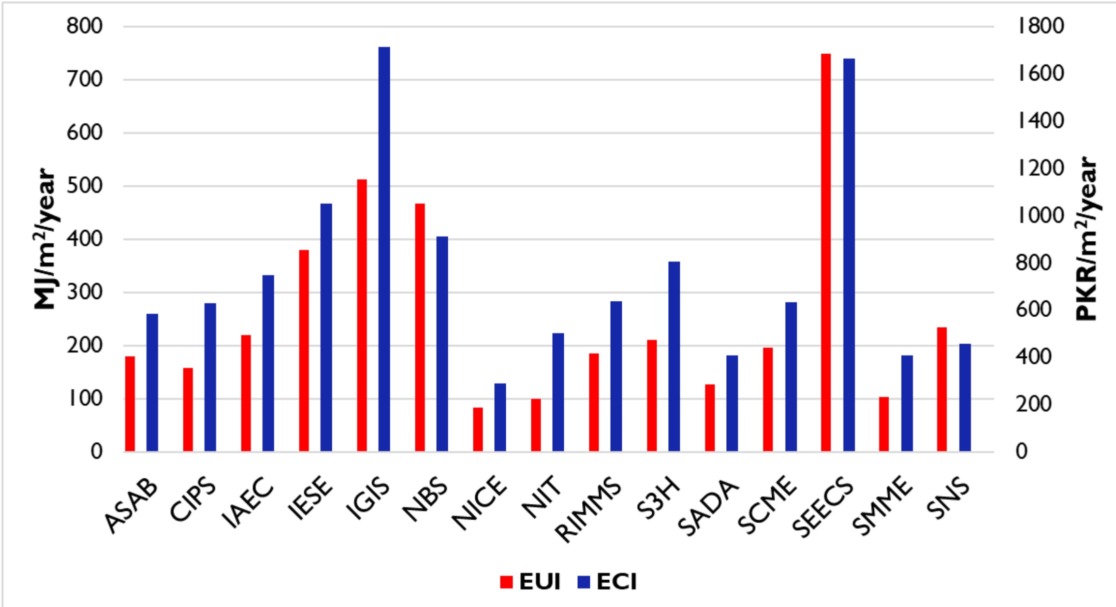

Figure 37 EUI and ECI of all academic buildings in NUST

Solar photovoltaic systems with a cumulative capacity of 2.9 MW were designed for rooftops and parking lots of all academic buildings in NUST using HelioScope software. These systems can generate over 4000 MWhs of clean electricity annually which is approximately equal to 40% of annual electricity consumption of NUST. By installing these photovoltaic systems, NUST can avoid 2 million kgCO_2 every year. To evaluate the financial feasibility of these systems System Advisor Model (SAM) was used. The results showed that such systems are both technically and financially feasible with quick payback of 5 to 6 years. Payback period of PV systems in the parking lot were slightly higher as they are costlier to install.

6.2 Recommendations

1. Smart meters should be installed in all buildings for continuous monitoring and recording of electric load in real time. This will give a deeper insight into how the building uses energy and hence provide more opportunities for reducing operational energy use.

2. A significant amount of energy can be saved by simple no cost measures or behavioral changes. This calls for raising awareness among building occupants about the energy use of the building and how can they influence it.
3. Building envelope should be designed to minimize the negative impact of external environment such as solar heat gain and infiltration. Double glazed windows, louvres and shades, PVC frames, insulation in walls and roofs and reflective paints should be considered during the design stage of a building.
4. All the appliances installed in buildings such as fans, lights, air-conditioners and other equipment should be energy efficient. This will lead to significant savings in energy costs over the lifetime of a building.
5. Renewable energy especially solar PV is a very feasible option for onsite systems. If a building meets its electricity requirements using a clean energy source such as solar PV, it can avoid grid electricity, most of which is produced by thermal powerplants run on fossil fuels. This can significantly reduce its carbon footprint and will provide monetary benefit as well.

Annex

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Design of an 87 kW Photovoltaic System for a University Building to Support LEED Certification

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Abstract
Leadership in Energy and Environmental Design (LEED) is one of the most popular green building assessment system developed by US Green Building Council (USGBC). US-Pakistan Center for Advanced Studies in Energy (USPCAS-E) aims to achieve LEED Certification for its building situated in NUST, Islamabad. This paper describes the design process of a Solar Photovoltaic (PV) system to meet some of the energy requirements of the building. An 87-kW system, designed by using Step Robotics solar site analysis tool, suggests that it can meet 17% of annual electricity demand of the building using solar energy. This will lead to reduced emissions and will enhance the energy performance of the building.

Keywords
Solar Photovoltaics, Leadership in Energy and Environmental Design (LEED), Site analysis, Shading, Sustainable Buildings

1. Introduction

Efforts have been initiated around the world to cut down carbon emissions in order to combat global warming. The current electricity generation mix of Pakistan is highly skewed towards thermal powerplants, mostly operated on imported fuel oil. In addition to the carbon emissions, such dependence imposes a huge burden on country's economy and makes our electricity sector vulnerable to the fluctuations in international oil market prices. To overcome the supply-demand gap, the use of indigenous energy sources should be encouraged with a special focus on renewable energy deployment. This will lead to enhanced energy security of the country.
Buildings account for about 40% of the total global energy consumption ("United Nations Environment Programme (UN Environment) Website," n.d.) and thus provide a huge opportunity for improvement through energy efficiency and conservation measures. Green and sustainable buildings is an actively progressing area and has seen a lot of development in the past few

decades. The Office of the Federal Environmental Executive defines green building as "the practice of 1) increasing the efficiency with which buildings and their sites use energy, water, and materials, and 2) reducing building impacts on human health and the environment, through better siting, design, construction, operation, maintenance, and removal — the complete building life cycle (Howard, 2003)." Many rating systems have been developed to assess green buildings around the world. LEED or Leadership in Energy and Environmental Design is a green certification program developed by US Green Building Council for the design, construction and operation of high-performance green buildings. It is considered as one of the most widely adopted green building assessment tool in the world with more than 93,000 registered and certified projects (Mao, Lu, & Li, 2009; "U.S. Green Building Council (USGBC) Website," n.d.). LEED is based on prerequisites and credits that a project meets to achieve a certification level: Certified, Silver, Gold and Platinum. LEED v4.1 is an incremental update to the previous version and it is claimed to be the most inclusive and transparent platform to date. LEED v4.1 certification for existing buildings is divided into seven categories; location and transportation, sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality and innovation. The energy and atmosphere category is accounted for the most points due to its huge impact on reducing greenhouse gas emissions ("U.S. Green Building Council (USGBC) Website," n.d.).

US-Pakistan Center for Advanced Studies in Energy located in National University of Sciences and Technology (Islamabad), was built utilizing the principles of green buildings. A project is underway which aims to achieve the LEED certification of this building for which energy performance of the building needs to be improved by deploying onsite renewable energy. Solar photovoltaic is a clean source of producing electricity which is modular, has short construction periods, requires little maintenance and is highly cost competitive. This paper discusses the design of 87 kW grid-tied solar PV system to partially meet the electricity demand of the building.

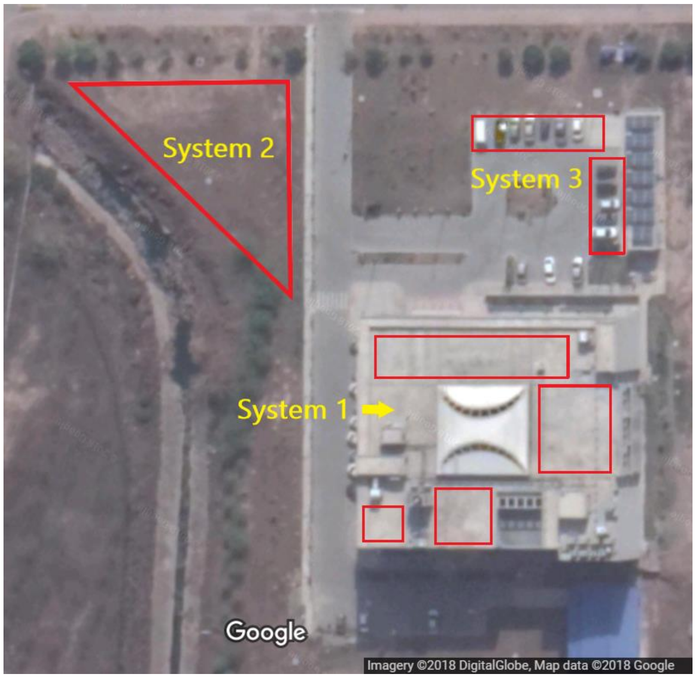


Figure 1: Satellite Image of USPCASE-NUST Building indicating Locations selected for PV Installation

2. Methodology

Numerous software tools are available for the design and performance analysis of solar PV systems for buildings. Performing such an analysis requires ground measured or satellite-based weather data, electrical consumption of the building and estimation of different loss factors associated with a PV system. Energy yield of a PV system is influenced by many factors including solar irradiance, temperature, soiling, degradation of its components and mismatch loss. A major loss in PV system output is shading from surrounding trees and objects. Therefore, it must be calculated as accurately as possible to get a true picture of the system output. This study makes use of Step Robotics platform ("Step Robotics Website," n.d.)(lens and smart phone application) for the onsite shading analysis of the system. Three locations are considered for the installation of PV modules; building rooftop, a vacant piece of land near the building and the parking lot, being named as system 1, system 2 and system 3 respectively (Figure 1). To maximize solar irradiance reaching the modules, the tilt angle is kept equal to the latitude i.e. 33°. Ideally, the azimuth angle should be 180° (south-facing system) but for simplicity and ease of installation it is kept 160°, aligned with the building orientation. The fish eye lens is attached to a smart phone and is used to capture skylines at the proposed system site. The application automatically detects sky and non-sky parts of the image and adjustments are made using manual shading analysis. Weather data from NASA website is used to predict the energy generated by the system. Inter-row spacing is calculated in such a way that an array does not shade the subsequent row.

Table 1: System Description

	System 1	**System 2**	**System 3**
System size	47.74 kW	27.28 kW	12.40 kW
Inverter	14 x Canadian Solar CSI-4000TL-CT (240V) 4.02 kW Inverter	8 x Canadian Solar CSI-4000TL-CT (240V) 4.02kW Inverter	4 x Canadian Solar CSI-4000TL-CT (208V) 3.81kW Inverter
Module	154 x Canadian Solar CS6X-310P Modules	88 x Canadian Solar CS6X-310P Modules	40 x Canadian Solar CS6X-310P Modules
Module tilt	33.6°	33.6°	33.6°
Module azimuth	160.5°	160.7°	160.8°
Annual Energy Generation	67,557 kWh	37,230 kWh	16,122 kWh
Capacity Factor	16.2%	15.6%	14.8%

Table 2: Module Electrical Parameters at Standard Test Conditions (STC)

Maximum power (Pmax)	310 W
Open circuit voltage (Voc)	44.9 V
Short circuit current (Isc)	9.08 A
Maximum power voltage (Vmax)	36.4 V
Maximum power current (Imax)	8.52 A
Module efficiency	16.16 %

3. Results and Discussion

Figure 2(a) shows monthly electricity consumption of the building and this usage profile is generated by the Step Solar application upon entering the estimated annual energy usage. Monthly energy generation of all the systems is given in Figure 2(b) and we can see that it follows the same trend as the consumption pattern. During hot summer months the electricity demand is high because of the cooling load. The PV system output during this time is also high due to high values of solar irradiance. The electricity consumption decreases as winter approaches. A battery bank was not considered for this system but if we have multiple sources of electricity like batteries, diesel generators, solar PV and grid electricity, then an intelligent dispatch strategy can be devised to minimize consumption of electricity from the grid and diesel generators.

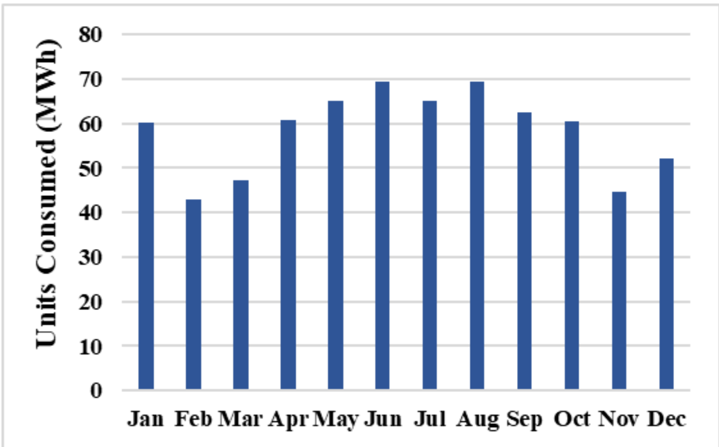


Figure 2(a): Monthly Electricity Consumption of USPCASE-NUST Building

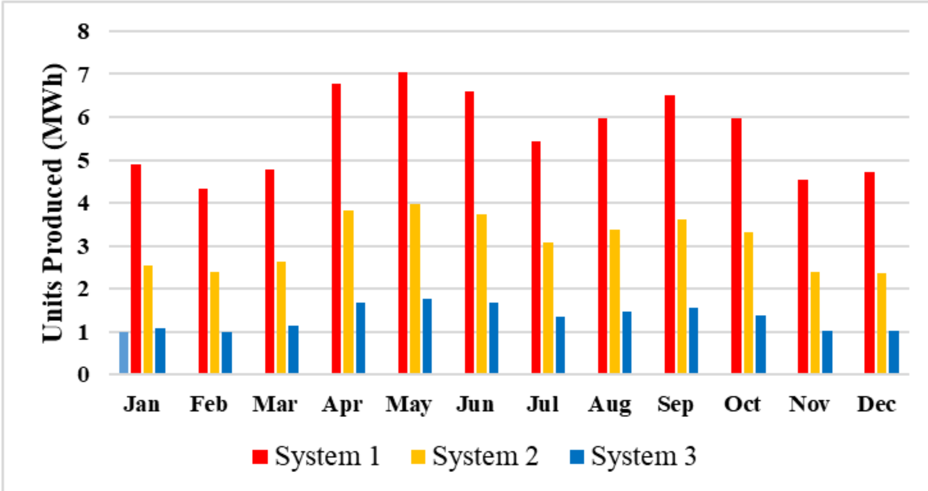
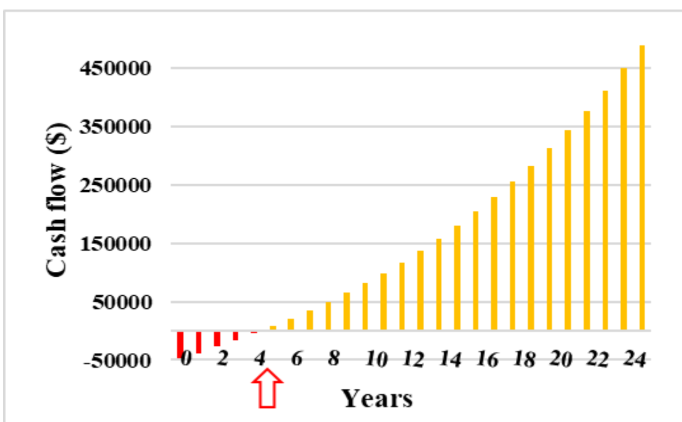
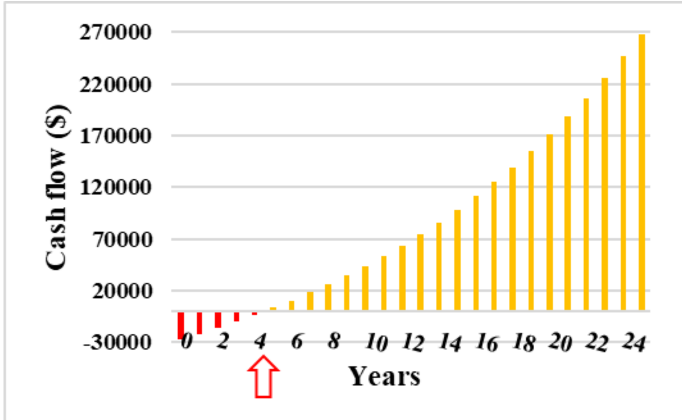


Figure 2(b): Monthly Electricity Production of Proposed Systems

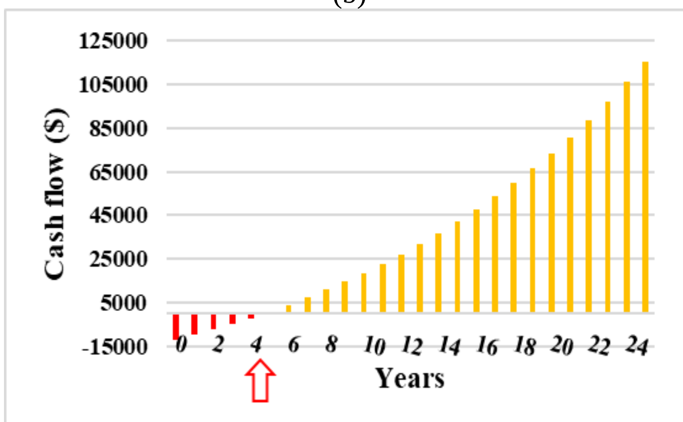
Table 1 shows the system parameters of all the three systems. Due to the presence of HVAC system components on the rooftop, some areas face high shading. These areas were avoided during system design. Based on the captured skylines of the site, Step Robotics application gives us the percentage solar access for each month which is accounted for while predicting the annual energy generation of the system. System 1 consists of four arrays in different regions of the roof. The cost of the system is $47,740 and the investment will pay for itself through savings in 4.4 years (Figure 3(a)). Annual electricity generation of the system will be 67,557 kWh which is about 10% of building electricity demand.



(a)



(b)



(c)

Figure 3: Cumulative Payback for all three Systems

System 2 will be a 27.28 kW solar PV system which will be installed to the east of the building as shown in Figure 1. According to the shading analysis performed using the step robotics lens it was found out that major obstruction will be trees but still the system will have 92.7 percent access to sunlight on average. The system will pay for itself in 4.5 years (Figure 3(b)). Annual production of this system will be 37230 kWh which will meet 5% of the building electricity demand. System 3 consists of two arrays. The shading analysis revealed that system will have 87.6 percent access to solar irradiance and due to this shading loss, the capacity factor of this system is less than the other two systems. The cost of the system is $12,400 and the payback period comes out to be 4.7 years (Figure 3(c)). The system will generate 16122 kWh annually which is 2% of the annual electricity consumption of the building.

4. Conclusions

Monitoring, assessment and reporting of sustainability initiatives is extremely important for continuous improvement. LEED provides such a platform for green buildings which is followed all over the world. Obtaining LEED Certification of a building requires its energy performance to be improved which can be achieved by renewable energy deployment. An 87-kW solar PV system designed by using Step Robotics solar site analysis tool has the potential to meet 17% of the annual electricity demand of USPCAS-E building. Financial analysis suggests it will payback for itself in less than 5 years. If a building meets its electricity requirements using a clean energy source such as solar PV, it can avoid grid electricity, most of which is produced by thermal powerplants run on fossil fuels. This can significantly reduce its carbon footprint and will provide monetary benefit as well. If higher education institutions in Pakistan follow this model, they can create public awareness, and this will set examples for others to follow.

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