Net Zero Energy Schools in Pakistan: Opportunities and Challenges

By

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Reg # 172580

Session 2016-18

Supervised by

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For the future of clean, green and infinite energy

Dedicated to….
My beloved Family, Mentor and Friends

Abstract

In this study, feasibility of school buildings in Pakistan to attain net zero energy status is assessed. Three different types of K-12 school's public, purpose built private school and house based private school were selected as a case study. Five public school buildings and two private schools were located in Islamabad and Rawalpindi respectively. For assessment of net zero energy potential, data of energy consumption for one-year was collected. Main energy sources of these schools were electricity, natural gas and fuel for backup generators. Survey of schools to collect data regarding its building infrastructure and energy consumption was performed to identify the measures that can be taken to reduce the energy consumption. ASHARE Level-1(Walk through) audit results showed that lighting, air conditioning and fans are the main load of the buildings so main focus of this study for energy efficiency measures was on these appliances. Onsite renewable energy potential of the schools is assessed considering climatic conditions by using Helioscope for photovoltaic system design for fulfilling the energy requirements of the school buildings. Net zero site energy calculations were performed to determine the potential of the buildings to achieve net zero energy status. Financial analysis of the energy efficient appliances and photovoltaic system using simple payback period is also calculated. Payback period for photovoltaic system range from 3 to 6 years. It is evident from the study that public school buildings and house based private school can achieve net zero site energy status because of low energy consumption requirements and in case of private owned high income community school, achieving net zero site energy is not possible due to large energy requirements to attain thermal comfort and inefficient use of energy.

Keywords

Net zero energy building, Renewable energy, Photovoltaic system, Payback period, Helioscope

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List of Abbreviations

NZEB	Net Zero Energy Building
PV	Photovoltaic System
ZEB	Zero Energy Buildings
NNZEBs	Nearly Net Zero Energy Buildings
NZEHs	Nearly Net Zero Energy Homes
HVAC	Heating Ventilation and Air Conditioning
EUI	Energy Utilization Index

List of Publications

- **Sadia Gul**, Waqas Ahmad Khalil, Sophia Owais, Rafia Akbar and Muhammad Bilal Sajid, **Energy Consumption Profile of a K-12 School Building and Identification of Energy Conservation and Energy Efficiency Measures** published in the Proceedings of First International Conference on High Performance Energy Efficient Buildings and Homes 2018, Lahore, Pakistan.

- Waqas Ahmad Khalil, **Sadia Gul**, Rafia Akbar, Sophia Owais, Dilshad Ahmed Khan and Muhammad Bilal Sajid, **Sustainable Residential Buildings in Pakistan: Challenges and Opportunities** published in the Proceedings of First International Conference on High Performance Energy Efficient Buildings and Homes 2018, Lahore, Pakistan.

Chapter 1

Introduction

Global warming is damaging the Earth's climate as well as the physical environment. The cause of global warming is the increasing quantity of greenhouse gases in our atmosphere produced by human activities, like the burning of fossil fuels or deforestation. Our planet is facing significant challenges in 21st century because energy consumption is expected to double globally during the 1st half of this century. Buildings account for 40% of the world energy consumption and contribute towards one-third of the greenhouse gas emissions. Currently 77% of the world energy is obtained from fossil fuels which plays significant role in greenhouse gas emissions. In Pakistan fossil fuels are the major source of energy generation. Due to increase in energy demand along with energy prices and depletion of conventional energy resources, energy conservation and introducing renewable technologies can help to meet the energy demand. Majority of the regions located in Pakistan have more than 300 sunny days in a year. Moreover, majority of buildings are not energy efficient and hence require large amount of energy to meet its cooling and heating demands.

1.1 Net Zero Energy Building worldwide

Main factors driving the focus of the world towards green buildings are climate change, reduction in renewable energy prices especially photovoltaic and increase in energy prices.[1] Net Zero Energy Buildings(NZEBs) are part of different world countries strategies for reducing their greenhouse gas emissions. According to Paris Agreement by 2050 near net zero emissions goal should be achieved for supporting a transition to clean economy and low carbon society

- By 2050 European Union has also committed to reduce their GHG emissions by 80-95% compared to pre-industrial level by cutting back in sectors like power generation, industry, transport, buildings, construction and agriculture.
- United States has a target of emissions reductions of 80 percent or more below 2005 levels by 2050 while Mexico's goal is 50% reduction of greenhouse gases by 2050 compared to the year 2000. And Canada's target is to reduce emissions by 80% compared to 2005 levels.

- Conservation of energy in building sector can play an important role in achieving this target. Moreover, World Green Building also set the target that by 2030 all new buildings must be net zero carbon and by 2050 all of the buildings must operate as net zero carbon [2].

1.2 Net Zero Energy Building

Net zero energy buildings measures buildings energy performance. Net zero energy building is a highly efficient and low energy buildings that, over the course of a year, produces from onsite renewable sources at least as much energy as it consumes. Net zero energy buildings promote reduction in energy consumption, greenhouse gas emissions and dependence on fossil fuels. Net zero energy buildings can be defined in several different ways, few of the commonly used are

- Nearly Zero Energy Buildings
- Net Zero Site Energy
- Net Zero Source Energy
- Net Zero Energy Cost
- Net Zero Energy Emissions

1.2.1 Nearly Zero Energy Buildings

A NZEB can produce 30 percent or more of its energy requirements through on-site renewable energy resources [3].

1.2.2 Net Zero Site Energy

Site energy means energy consumed and generated on site. A net zero site energy building produces at least as much energy as it consumes over a period of a year, when accounted at site. In these buildings, building has to generate a unit of energy for every unit of energy they consume [4]. This is the most commonly understood and used definition of net zero energy building as it uses metered data for calculation. On the other hand, it’s one of the most difficult to achieve [5].

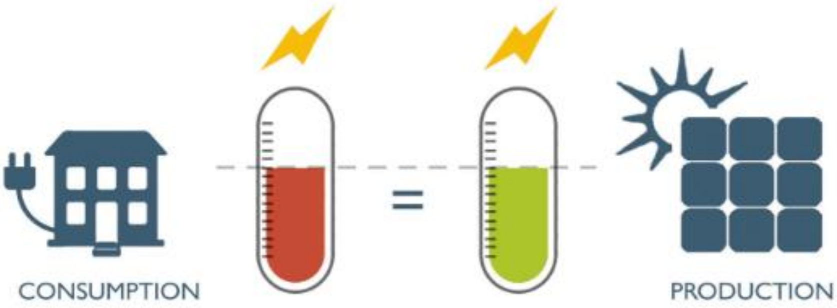

Figure 0-1. Net zero site energy [6]

1.2.3 Net Zero Source Energy

A zero energy building in which on source energy basis, actual annual energy delivered to the building is equal to or less than on-site renewable energy exported [7]. Source energy refers to the energy needed to extract and deliver energy to a site, including the energy that might have lost during generation, transmission and distribution process [4].

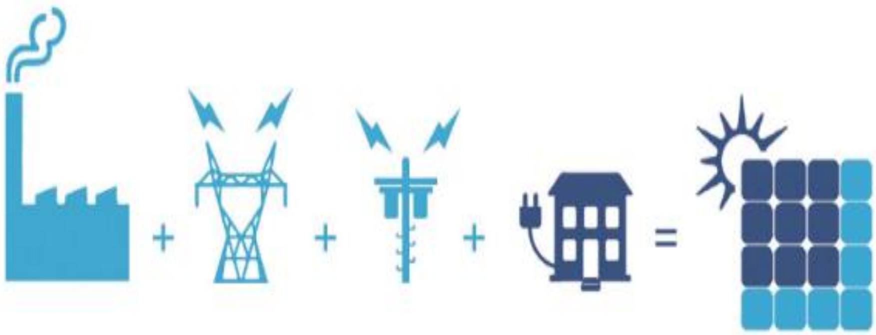

Figure 0-2. Net zero source energy[6]

1.2.4 Net Zero Energy Cost

In net zero energy cost building, the money that building owner/resident provide to local utility service for getting energy services is nearly equal to the amount the company pays the building owner/resident for the exported energy from grid over the course of year. All service and energy charges on the utility bill should be incorporated in case of delivered energy.

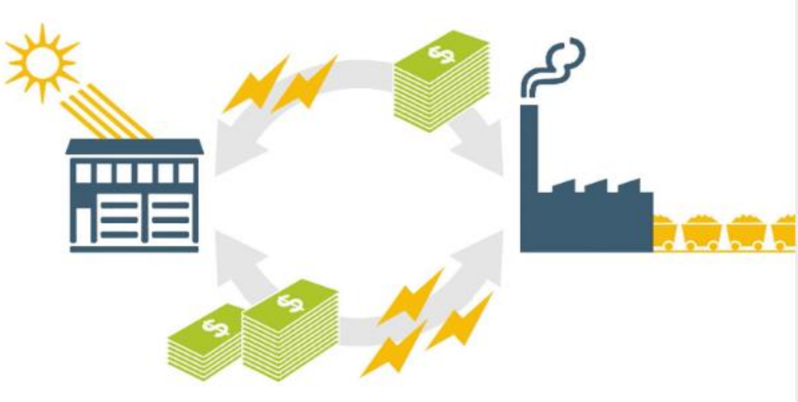

Figure 0-3. Net zero energy cost[6]

1.2.5 Net Zero Energy Emissions

A building that generates or purchase at least as much emission free energy from renewable sources as much it consumes from non-renewable sources over a period of a year. Energy can be generated both on-site and off-site.

1.3 Role of Net Zero Energy in School

Schools buildings have huge potential to be ZEB with appropriate energy utilization techniques due to low energy demand. As they have short working hours, long vacations and operate only for nine months. Their occupancy levels are constant and have high renewable energy potential. We can easily utilize solar energy as most of the school's energy demand comes during the day. Net zero energy schools can act as living labs for promoting this idea. However, energy consumption of schools represents the second highest operational expense next to salaries. So implementing net zero energy school concept will provide benefits that extend far beyond energy cost savings like improved health, increased productivity, sustainable future and amplification effect on other buildings along with reduced carbon footprint.

Education sector is an integral part of a state and Pakistan being a majorly populated state has large number of schools. Various studies around the world have been done on NZEBs but they don't reflect the energy scenario and climatic conditions of Pakistan. This is the first study in which school stock of Pakistan is being studied as no prior statistical data existed for these buildings. Main objective of this study is to determine the feasibility of net zero energy school buildings in Pakistan and to observe that how closely these educational buildings can achieve the status of net zero energy.

Pakistan has 303346 schools out of which 191065 are public schools and 112381 private schools. Islamabad has total of 1606 educational institutes which are divided into urban and rural areas. For this study I chose five public school buildings in Islamabad among 278 schools [8] as they represent significant building school stock in urban areas of Pakistan. Results of these buildings analysis is then compared with two private school buildings. Private schools are of basically two types, purpose built campuses and house based school buildings.

1.4 Objectives

- Performing energy audit for estimating energy requirements and its conservation of school buildings
- Determination of onsite renewable energy potential
- Assessment of NZES potential
- Identification of feasible financial solution

1.5 Organization of Thesis

Chapter 1 gives the introduction of the thesis; provides background of the problem and objectives of research.

In Chapter 2, the literature review related to different aspects of NZEBs is discussed. The particular focus is on energy consumption, retrofitting measures and economic analysis.

Chapter 3 gives details of the methodology followed for NZES calculations.

In Chapter 4, the results for public schools, purpose built private school and house based school are discussed.

In Chapter 5, conclusion of the work is presented.

Summary

Net zero energy building is a highly efficient and low energy buildings that, over the course of a year, produces from onsite renewable sources at least as much energy as it consumes. Main factors driving the focus of the world towards green buildings are climate change, reduction in renewable energy prices especially photovoltaic and increase in energy prices. Net zero energy buildings can be defined in several different ways, few of the commonly used are Nearly Zero Energy Buildings, Net Zero Site Energy, Net Zero Source Energy, Net Zero Energy Cost and Net Zero Energy Emissions.

Schools buildings have huge potential to be ZEB with appropriate energy utilization techniques due to low energy demand and also energy consumption of schools represents the second highest operational expense next to salaries. So implementing net zero energy school concept will provide benefits that extend far beyond energy cost savings like improved health, increased productivity, sustainable future and reduced carbon footprint.

This is the first study in which school stock of Pakistan is being studied as no prior statistical data existed for these buildings and main objective of this study is to determine the feasibility of net zero energy school buildings in Pakistan.

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Chapter 2

Literature Review

This chapter summarizes the work done related to Net Zero Energy Buildings(NZEBs) in different countries under different climatic conditions.

2.1 Energy Consumption

For transforming an existing building into NZEB, estimation of its energy consumption data is an important step. Mohamed M. Ouf et al. performed a first ever empirical study on energy consumption data of ten-years of 30 schools in cold climate of Manitoba, Canada. Results showed significant impact of the buildings age on energy consumption, as new buildings consume more electricity than gas as compared to old and middle aged buildings. Retrofitting measures reduce energy consumption, but they don't have statistically significant effect on consumption. There were other factors that might have effect on energy consumption of the school buildings but due to unavailability of information about them in school records they were ignored [1]. In one other research, Jen Chun Wang studied energy performance of school buildings in Taiwan. In his study he collected data of fifty-one universities and several high, middle and elementary schools. Average energy use per person was high for universities as compared to schools as universities rely on air conditioning for comfortable indoor environment and have additional research and testing equipment. Moreover, it was observed that academic research and development universities have higher energy consumption as compared to those which are solely for teaching purposes and public universities have high consumption compared to private universities. In school buildings lighting and air conditioning are the main factors [2]. Energy consumption of ten different schools in Daegu, South Korea was analyzed on unit area, per capita and yearly bases by Kim Tae-Woo et al. It was concluded that by energy type, electricity was the dominant one among electricity, oil and gas and its use is increasing because of replacement of heating and cooling equipment with electric systems. Energy consumption was highest in the months of December and lowest in January and August. In terms of energy use, heating consumes most of the energy and monthly per capita consumption was calculated to be 151-403MJ/student [3].

Climate effects the energy consumption of a building, as energy requirements vary according to climate. A study was conducted in three different climatic conditions of Cyprus to compare the structural elements and energy consumption of a building. It was concluded that insulation of the building and HVAC system are the most important considerations in energy efficiency of a school. Energy efficient features of the buildings include horizontal roof, single story, and rectangular design. Furthermore, energy consumption of the building also depends on number of users and their behavior and it can be reduced by using "Energy Star" rated electrical appliances [4]. Siwei Lou et al. studied the energy consumption and production of an educational building in hot and humid climate of Hong Kong and performed analysis on energy modeling software eQUEST. They observed that energy can be saved by improving building envelope and utilization of energy efficient lighting and air conditioning systems, and 97.5% of the remaining energy requirements can be fulfilled by utilizing building integrated photovoltaics. Furthermore, school can achieve net zero energy status by installation of rooftop photovoltaics for fulfilling the remaining energy needs [5].

2.2 Retrofitting Measures

Retrofitting measures for reduction in energy consumption is the second step after energy consumption analysis. Francesco Causone et al. simulated the energy retrofitting of a Kindergarten by using Energy Plus software to achieve the target of net zero energy. Low performance of the building envelope, heating, lighting system and ventilation was evident from its analysis. 85 percent reduction in energy requirements was observed in heating and cooling energy requirements along with improvement in indoor environment quality as compared to pre-retrofitting conditions [6].

Simone Ferrari et al. selected a building in the campus of Politecnico di Milano University, Italy to conduct a study on improving the energy performance of an office building by retrofitting measures. Effect of reduction in greenhouse gas emissions, energy and cost savings was considered while proposing different improvement measures like thermal insulation, upgradation of HVAC system, installation of advanced lighting controls and solar photovoltaic. Results of the study demonstrates that implementation of different well proven technologies available in the market can reduce greenhouse gas emissions by 40% and economic issues are the key factor in retrofitting strategies for existing buildings [7].

2.3 Economic Analysis

Economic analysis is an important aspect that influences various decisions during design phase of a new building and retrofitting phase of existing buildings. Ali AlAjmi et al. proposed three scenarios for an educational building utilizing the same roof area for achieving net zero energy in hot and arid climate of Kuwait. For this purpose, Energy Plus software was used for energy simulations and three energy efficiency measures were implemented after performing the audit of the building, which resulted in 658.8 MWh of annual energy savings. Fist scenario includes design of a solar photovoltaic system for fulfilling the annual energy requirements of the building. Second scenario was to use more efficient chillers to reduce the consumption further along with the same PV system designed in the first case. In third scenario solar absorption chillers and solar photovoltaic system was sized according to the energy requirements of the building. First scenario only attains net zero status on annual basis while other two can achieve net zero energy on both monthly and annual bases. This study also proposes that investment is an important factor for transforming a building into NZEB [8].

The objective of the study conducted by Daniele Teste et al. was to analyze the feasibility of the retrofitting measures of an educational building for transforming it into NZEB. A three story school building in Pisa was selected as a case study for analyzing criticalities associated with Italian legislation on NZEBs, according to which, for a building to attain net zero energy status, it has to be compared with a reference building. Because of the unavailability of sufficient number of buildings for study; bottom up approach by taking reference building as a case study was adopted. For this purpose, they performed energy audit of the building along with simulation of retrofitting measures considering both energy and economic aspects. Analysis was performed by two energy models by using Edilclima and open access SEAS software. Simulation results by Edilclima shows overestimation of the energy consumption due to its intermittent use and long payback periods were observed because of low yearly energy consumption [9].

2.4 Performance of NZEB

Difference in actual performance of a designed NZEB was studied by Zhihua Zhou et al. They investigated the actual performance of an office building designed to be net zero energy in Tianjin, China. During design phase energy consumption of the building and generation capacity of the photovoltaic system was estimated by simulations. Actual performance of the building for two years shows underestimation of the energy consumption during simulations because of different equipment type and its operation time between design and operational phase. Occupants' behavior and degradation of solar photovoltaics were also the contributing factors for the difference in energy consumption and generation. This research also reveals that for accurate photovoltaics generation capacity estimation, most recent meteorological data of the irradiations should be used [10].

Walter D. Thomas et al. conducted a study in New England to measure the performance of a net zero energy homes and nearly net zero energy homes. Twenty houses which were particularly designed as NZEHs or NNZEHS were monitored for a period of 12 months for gathering data of consumption and production of energy along with cost. Custom models for the prediction of energy consumption and production were developed and comparison between the predicted and measured values was performed. It was observed that in cold climatic conditions of England those houses can meet or exceed the designed energy performance although their performance differs from the designed [11].

2.5 Indoor Environment Quality

Indoor environment quality is also widely studied factor along with energy consumption as energy efficiency and conservation measures affect the indoor environment quality. Weim Zeiler et al. analyzed the first net zero energy school designed in Netherlands and compared its performance with traditional school buildings. Focus of this study was on indoor environment quality and thermal comfort of the building. Different measures were taken for a period of one week. ZEB results show better thermal comfort and IEQ than traditional school buildings but humidity levels perceived by teachers were worse as ventilation rate was controlled by carbon dioxide concentration, and low ventilation rates were not enough to dispose of the odors in the class [12].

Milad Golshan et al. in Netherlands conducted a study focused on environmental conditions in schools. Ten efficient schools from the list of top 15 energy conscious schools of the 2016 were selected for thermal comfort and indoor air quality evaluation in comparison to heating/cooling and ventilation energy consumption. It was observed that indoor air quality was a neglected area in efficient schools as compared to energy efficiency [13].

2.6 Global Perspective

Net zero energy buildings concept has emerged in recent years and its models are being studied worldwide. But in some countries NZEBs concept is at early stages of development. Like Mansi Jain et al. conducted a study in India and focus of the research was to assess the status of NZEBs in India. An integrated framework called Sectoral System Innovation Assessment Framework (SSIAF) was used to analyze seven demonstration projects. SSIAF is based on five key components including shaping of expectations, actor network formation, learning processes, institutional alignment and market demand creation. So far, it was observed that there is low level of demand for innovation, high level of interaction among project team member and building institutions are not well aligned with NZEBs sector. It was concluded that NZEBs niche is yet to be develop and mature in India [14].

Although Australia has high renewables penetration but contrary to this Lousie Wells et al. stated that the concept of net zero energy buildings is anonymous for the majorities due to lack of policies. They discussed the work and NZEBs policies implemented worldwide and also highlighted various limitations like lack of universal definition for NZEBs and inconsistent energy efficiency standards for actualization of the NZEBs concept [15].

Summary

Detailed literature review, addressing different aspects like energy consumption, retrofitting measures, economic analysis, indoor environment and actual performance of the NZEBs in different countries under different climatic conditions is discussed in this chapter.

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Chapter 3

Methodology

This chapter describes the overall methodology to achieve the objective of this study. In order for a building to achieve net zero energy target, analysis of the energy requirements and load pattern of the school will be performed. Furthermore, onsite renewable energy potential of the school will be assessed for fulfilling the energy requirements. In the end, the most appropriate financing plan to accomplish net zero energy school building will be developed. Five public school buildings and two private school buildings representing the main categories public school, purpose built private school and house based private school were selected. Methodology described below is followed for all schools.

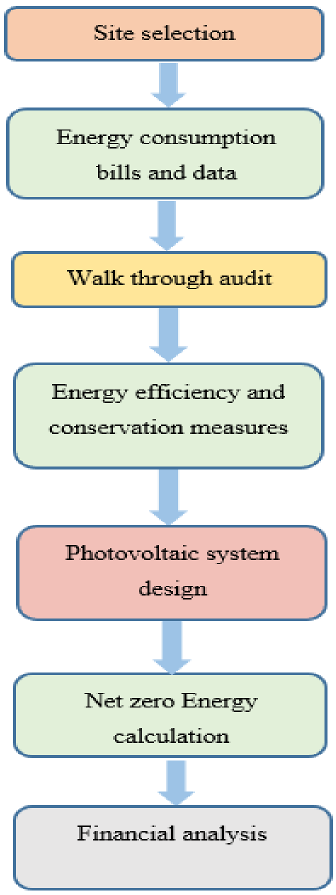

Figure 3-1. Work Methodology

3.1 Site Selection

Public school building in Islamabad was selected as a case study for transforming it into Net Zero Energy buildings (NZEBs). School was a single story building consisting of 27 class rooms, several offices, store rooms, exam hall, library and computer lab.

3.2 Energy Consumption Bills and Data Processing

As school only use electricity and natural gas so utility bills for one year were collected for them. Annual consumption of both sources is calculated using MS Excel.

3.3 Walk through Audit

Survey of school to collect data regarding its building infrastructure and energy consumption was performed, purpose of which was to identify the measures that can be taken to reduce the energy consumption. Data regarding number and type of appliances is collected. Interviews of different people like teachers and management staff were conducted to know the usage time of appliances. Data collected of the appliances is shown in Table 1. Other space type includes kitchen, store room and restrooms. Other appliances include printer, refrigerator, water pump, water cooler and exhaust.

Figure 3-2. Class room view of one of the selected school

Table 3-1. Public schools' buildings audit

	Class rooms	Office	Corridors	Labs	Others
School-1					
Lights	89	12	20	3	4
Fans	87	10	-	3	-
Computers	-	1	-	20	-
Other appliances	-	1	-	2	1
School-2					
Lights	105	22	43	36	24
Fans	84	14		28	13
Computers	-	1		27	-
Other appliances	-	1	3	1	4
School-3					
Lights	96	31	47	69	29
Fans	96	19	-	51	8
Computers	-	2	-	-	-
Other appliances	-	2	4	4	-
School-4					
Lights	105	26	44	25	60
Fans	110	19	-	16	28
Computers	-	-	-	20	-
Other appliances	-	3	2	-	-
School-5					
Lights	72	13	30	-	26
Fans	72	11	-	-	18
Computers	-	1	-	-	-
Other appliances	-	2	2	-	1

Table 3-2 shows the results of the audit of the purpose built private school building. Other areas include gym, restrooms, store room, art room, music room, sport room, prayer room, doctor room and kitchen. And other appliances in the table include computers, printers, water coolers, oven, electric kettle, scanner, dispenser, hand dryers, refrigerators, water pump, room cooler etc.

Table 3-2: Private School-1 audit

	Class Rooms	Staff Rooms	Office	Labs	Corridor	Residential	Cafe	Others
LED	-	-	-	-	22	1	-	-
Energy Saver	-	-	-	-	58	5	1	-
Tube Lights	222	43	13	42	5	2	100	79
Fans	146	26	7	22	7	4	3	39
Old AC	23	7	2	5	-	-	-	9
DC Inverter AC	14	1	1	-	-	-	-	-
Other		2	10	63	6	4	1	33

Table 3-3. Private School-2 audit

	Office	Class room	Corridor	Other
Energy Saver	2	53	15	8
Tube light	1	17	1	1
LED		19	5	-
Fan	1	41	7	
Exhaust	-	13	4	2
Others	2	-	-	-

3.4 Energy Efficiency and Conservation Measures

Energy efficiency and conservation measures include no cost, low cost and capital intensive measures. No cost measures include turning off all electrical appliances when not in use, turning off the lights when daylight is available and closing all doors and windows when air conditioners are ON. Low cost measures include occupancy sensors installation in less frequent use areas, use of blinds and shades on windows, plugging air leaks of the windows and doors, regular maintenance of the heating and cooling equipment. Capital intensive measures include roof insulation and reflective roof coating. Efficient appliances like lightning, fans and air conditioners.

At present energy efficient appliances are being introduced in the market which have reduced environmental footprint and are also economically beneficial. In Pakistan energy efficient air conditioners, fans, lights and other electrical appliances are available. In this study only air conditioners, fans and lights are considered as main electrical load of the school buildings was because of air conditioners, fans and lights. At present in public school's energy efficient fans and LED lights are installed so no calculations were performed. However, calculations were performed for Private School-1 because of the air conditioners as its main load and of Private School-2 main load was because of inefficient fans.

3.5 Photovoltaic System Design

Onsite renewable energy potential for installation of solar photovoltaic system was assessed during walk through audit. After wards photovoltaic system was designed by using Helioscope software. Helioscope is solar system design software which use live Google maps of the location for simulations. Detailed system plan including suitable site, orientation, types of panels and other requirements related to system installation.

3.6 Net Zero Energy Calculations

3.6.1 Net Zero Site Energy

For net zero site energy, only the annual energy delivered to the building is calculated from all sources. On utility bills natural gas consumption was given in terms of volume is converted in units of energy by using conversion factor $1\text{Hm}^3 = 3700\text{MJ}$.

Figure 3-3. Rooftop view of one of the selected school

Net zero site energy is calculated by using equation 1.

$$Esite = \Sigma_i(E_{del,i}) - \Sigma_i(E_{exp,i}) \qquad (1)$$

$E_{del,i}$ is delivered energy for energy type i. $\boldsymbol{E_{exp,i}}$ is the exported on-site renewable energy for energy type i. Where, i can be electricity, natural gas or generator fuel.

3.6.2 Net Zero Source Energy

For net zero source energy building calculations, source energy is calculated by multiplying conversion factor to the annual delivered energy from all the sources to the building and annual exported energy from the building. Equation 3 represents the equation used for net zero source energy [1].

$$Esource = \Sigma_i(E_{del,i} * r_{del,i}) - \Sigma_i(E_{exp,i} * r_{exp,i}) \qquad (2)$$

$E_{del,i}$ is delivered energy for energy type i, $\boldsymbol{r_{del,i}}$ is source energy conversion factor for the delivered energy type i, $\boldsymbol{E_{exp,i}}$ is the exported on-site renewable energy for energy type i, and $\boldsymbol{r_{exp,i}}$ is source energy conversion factor for exported energy.

3.6.3 Net Zero Energy Cost

Net zero energy cost of the building is calculated by subtracting annual cost of the energy exported by the building from annual cost of the energy delivered to the building including all charges by the utility provider. Net zero energy cost is calculated by equation 3.

$$Ecost = \Sigma_i(C_{del,i}) - \Sigma_i(C_{exp,i}) \qquad (3)$$

$C_{del,i}$ is the cost of the annual delivered energy and $\boldsymbol{C_{exp,i}}$ is the cost of the annual exported on-site renewable energy for energy type i.

3.6.4 Net Zero Energy Emissions

Net zero energy emissions is calculated by equation 4. In net zero emissions, annual delivered energy to the building is multiplied by an emission factor. Emission factor for different sources are different, it depends on the energy mix of a country in case of electricity. According to Pakistan energy mix 0.473kg CO_2/kWh is the emission factor for electricity [2] and 56.1kg CO_2/GJ, 74.1kg CO_2/GJ, 69.374kg CO_2/GJ for natural gas, diesel and petrol respectively. For photovoltaic system energy generation emissions reduction calculations, its generation will be multiplied with the same emission factor used for grid electricity.

$$Eemissions = \Sigma_i(E_{del,i} * e_{del,i}) - \Sigma_i(E_{exp,i} * e_{exp,i}) \qquad (4)$$

Where, $E_{del,i}$ is delivered energy for energy type i, $\boldsymbol{e_{del,i}}$ is source energy emission factor for the delivered energy type i, $\boldsymbol{E_{exp,i}}$ is the exported on-site renewable energy for energy type i and $\boldsymbol{e_{exp,i}}$ is source energy emission factor for exported energy.

3.7 Financial analysis

Financial analysis for both energy efficiency measures and photovoltaic system was performed using simple payback period. Simple payback period can be calculated as,

Simple Payback = Cost of energy efficient appliances / Annual electricity savings

$$\text{Annual Electricity Savings} = \frac{\text{(Daily hours' x 365 days/year) x Watts saved}}{1000} \times \frac{\text{Cost}}{\text{kWh}}$$

Summary

In order to achieve net zero energy, analysis of the energy requirements and load pattern of the school is performed. First step is to conduct survey of school to collect data regarding its building infrastructure and energy consumption. In order to increase the energy efficiency of the building, energy audit identifies the measures that can be taken to reduce the energy consumption. Onsite renewable energy potential of the school is assessed using Helioscope which includes suitable site, orientation, types of panels and other requirements related to system installation for fulfilling the energy requirements. In the end, financial analysis of the energy efficiency measures and PV system installation is performed.

References

[1] P. Torcellini *et al.*, “A COMMON DEFINITION FOR ZERO ENERGY BUILDINGS,” 2015.

[2] A. M. Brander *et al.*, “Electricity-specific emission factors for grid electricity,” *Ecometrica*, no. August, pp. 1–22, 2011.

Chapter 4

Results and Discussion

4.1 Public Schools

One-year electricity and natural gas bills were collected for all schools to calculate total annual energy consumption; natural gas was found to be a dominant factor of energy consumption. Natural gas is only used for cooking in the kitchens and cafe. All schools remain close from the second week of June to mid of August due to summer vacations. Unusual peak months were observed in all schools.

4.1.1 Assessment of Net Zero Energy Potential of School-1

4.1.1.1 Annual Electricity Consumption

Total energy consumption of 11902 kWh was calculated. Electricity consumption peak can be observed in the month of September i.e. 1835 kWh followed by 1460kWh in August. Despite summer vacations, unusual high consumption in June and July of 787kWh and 991kWh were observed respectively.

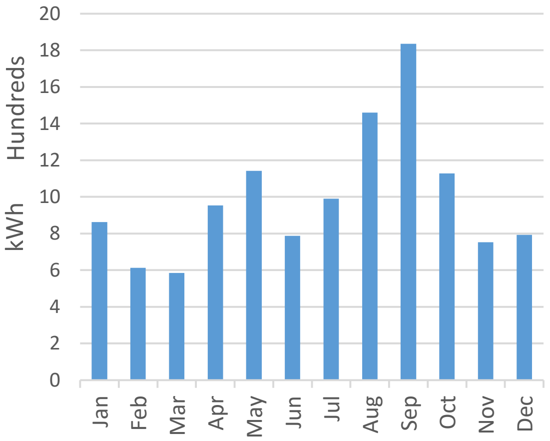

Figure 4-1. Annual electricity consumption

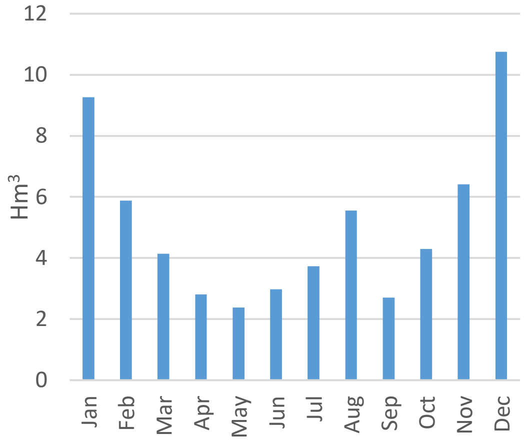

Figure 4-2. Annual gas consumption

4.1.1.2 Annual Gas Consumption

Total annual consumption of 60.86 Hm^3 was calculated. It can be seen from the graphs in the figure 2 that gas consumption is gradually increasing from September and is at its maximum 10.754 Hm^3 in December and gradually decrease till May.

Unusual high consumption with 5.555 Hm^3 in the month of August along with 3.724 Hm^3 in July and 2.974 Hm^3 in June although it is only used in kitchen.

4.1.1.3 Annual Energy Consumption

Total annual energy consumption of 268058.8MJ is calculated from both energy sources. In figure 3, it can be seen that natural gas with 225211.6MJ annual consumption is the dominant factor. Total energy consumptions peak can be observed in the month of December due to high natural gas consumption.

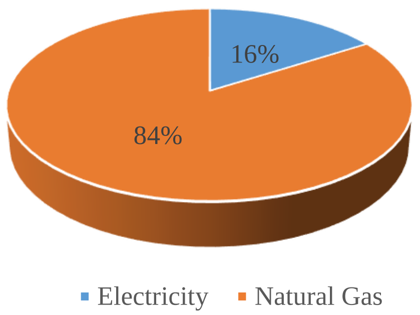

Figure 4-3:Annual energy consumption breakdown on the basis of sources

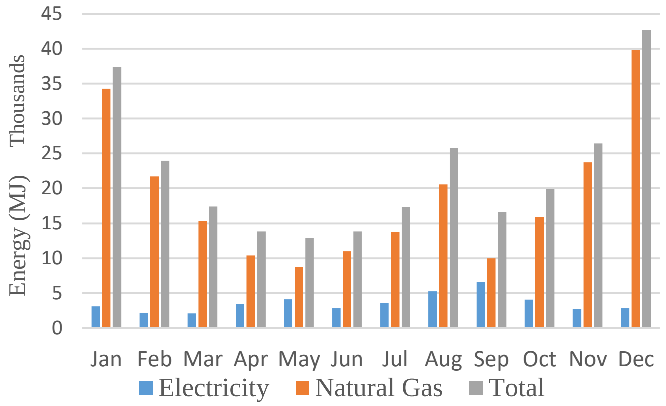

Figure 4-4:Annual energy consumption

4.1.1.4 Cost Analysis

Total annual cost of energy consumption is 376232 Rupees. On contrary to the energy consumption, in terms of cost electricity lead natural gas with 57 % of total annual cost. From figure 6 huge difference between the electricity consumption and its cost is obvious as compared to natural gas.

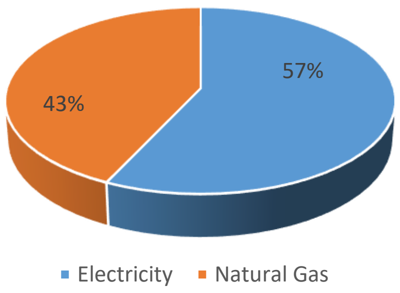

Figure 4-5:Cost breakdown on the basis of sources

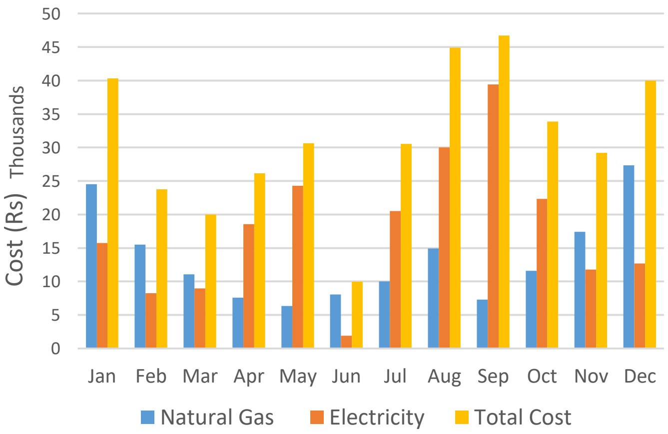

Figure 4-6:Total annual cost

If we analyze energy consumption in terms of cost, due to higher electricity prices, maximum cost in the month of August and September can be seen in figure 4-6. However, due to increased natural gas consumption in the month of December and January, high cost is also observed.

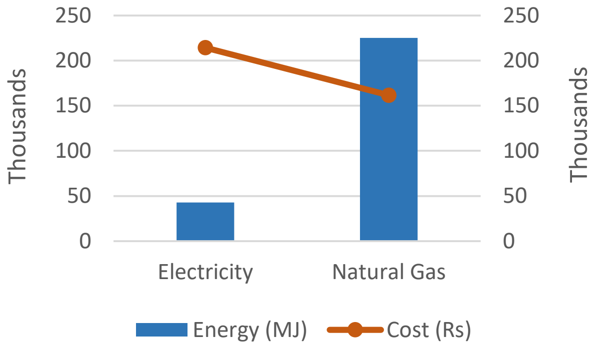

Figure 4-7:Comparison between energy consumption and cost

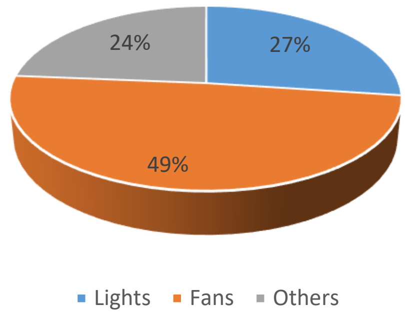

Figure 4-8:Load distribution of school-1

4.1.1.5 Audit of the School

School daily opens for 6 hours and five days a week. Audit results show that 76% of the total school load is due to the fans and lights. Fans use start from the month of March till October. School has enough day lighting because of big windows in class rooms so use of lights is not much.

4.1.1.6 PV System

Photovoltaic system was designed using Helioscope whose results are within 1% agreement of PVSyst software[1]. Maximum capacity of the rooftop. 141kW system with annual production capacity of 224MWh was designed using 434 mono c-silicon 325 watts' panels.

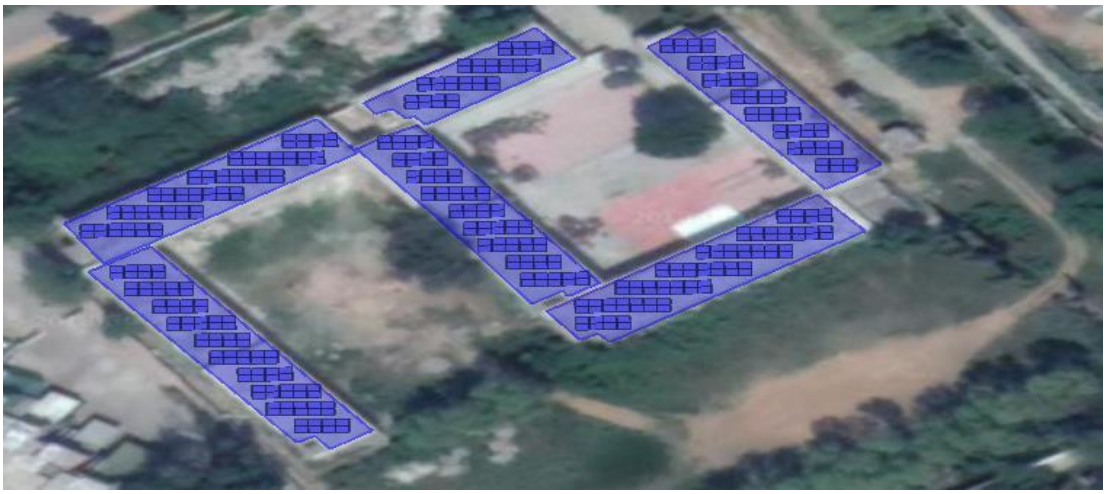

Figure 4-9: Helioscope photovoltaic system layout

Comparison between energy consumption and production is performed on monthly basis in figure 4-10. It is apparent from the figure that designed photovoltaic system can easily fulfill the monthly energy requirements of the school building.

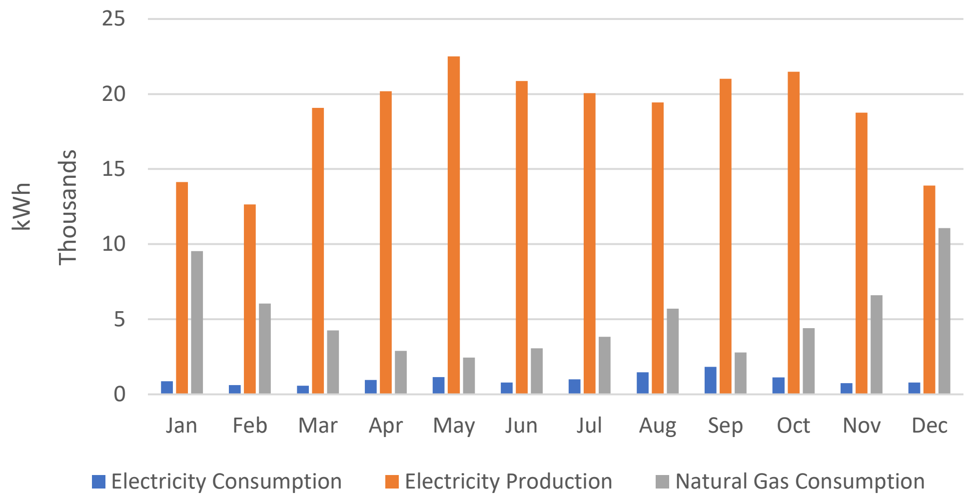

Figure 4-10:Comparison between annual energy consumption and generation

4.1.1.7 Financial Analysis of PV system

Cost of the PV system is calculated considering all the charges of accessories. Payback period was calculated using degradation rate of 1% and annual electricity increment of 15% [2].

Table 4-1: Financial analysis of PV system for School-1

PV System Capacity	150kW
Total No of Solar Panels(325W)	434
Cost of Solar Panels	8,463,000 Rs
Number of Inverters(50kW)	3
Cost of Inverters	33,00,000 Rs
Other Accessories	1,764,500 Rs
Total Cost of the System	13,527,500 Rs
Payback Period	4-5 years

4.1.1.8 Net Zero Energy

For a building to be net zero site energy its exported energy should be at least equal to or greater than the delivered energy to the building. School-1 total annual energy consumption is 268058.8MJ or 74.52MWh and its generation potential is 224MWh. School has the capacity to produce 149MWh more energy than its requirement. So

School-1 can easily achieve the net zero energy target. From table 4-2 it can be seen that School-1 can achieve all types of zero energy targets.

Table 4-2:Net zero energy calculations for School-1

TYPE	Delivered	Exported	Net Zero
Net zero site energy	74.52MWh	224MWh	-149.48MWh
Net zero source energy	105.73MWh	705.69MWh	-599.96MWh
Net zero energy cost	376232Rs	2083460Rs	-1707228Rs
Net zero emissions energy	18263.9831Kg	105965.244Kg	-87701.26Kg

4.1.2 Assessment of Net Zero Energy Potential of School-2

4.1.2.1 Annual Electricity Consumption

Total energy consumption of 17498 kWh was calculated from September 2017 to August 2018. Electricity consumption peak can be observed in the month of August i.e. 2,207 kWh whereas minimum was in November i.e. 949kWh. During this time period renovation work is being carried out in school so electricity consumption is high even in winter months and during summer vacations.

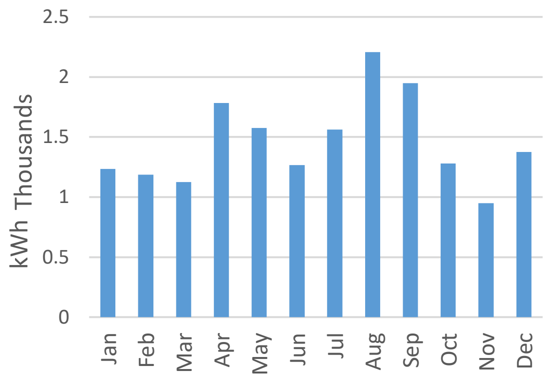

Figure 4-11. Annual electricity consumption

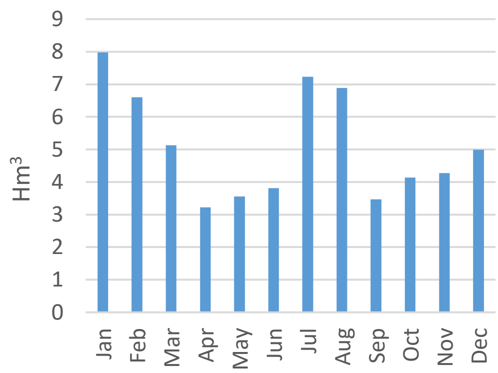

Figure 4-12. Annual gas consumption

4.1.2.2 Annual Gas Consumption

Total annual consumption of 61.286 Hm^3 was calculated and gas is used for cooking in the kitchen and café for a whole year and also for heating in winters in daycare center of the school. Gas consumption peak can be observed in the month of January i.e. 7.981Hm^3 whereas unusual peaks in July 7.229 Hm^3 and August 6.884 Hm^3 are also observed.

4.1.2.3 Total Energy Consumption

Natural gas takes over electricity in terms of energy with 226758.2MJ out of total 289,751MJ. In figure 4-14 peaks in July, August and January can be observed due to high natural gas consumption during these months.

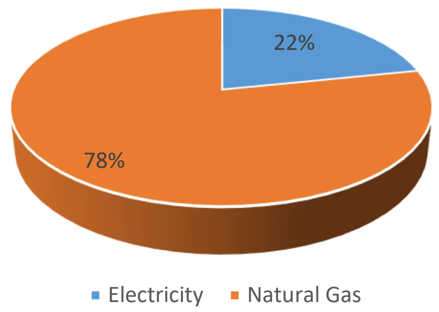

Figure 4-13: Energy breakdown on the basis of sources.

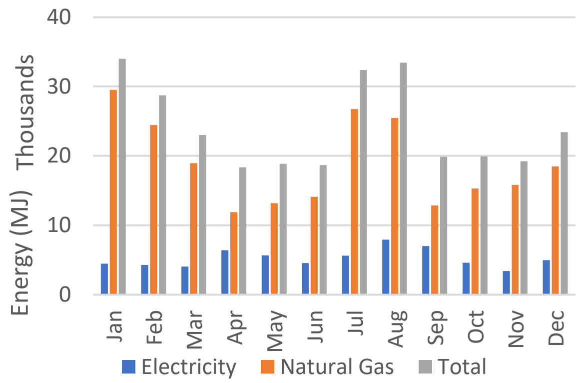

Figure 4-14:Total annual energy consumption

4.1.2.4 Cost Analysis

Electricity contributes to 63% of the total annual cost with 283673 Rupees. In figure 4-17 it is shown that natural gas contributes only 163973Rs to annual cost and its annual energy contribution is more than its cost. Monthly cost analysis shows maximum cost in the month of August and minimum in November. Due to mild weather in November consumption of electricity and natural gas is less.

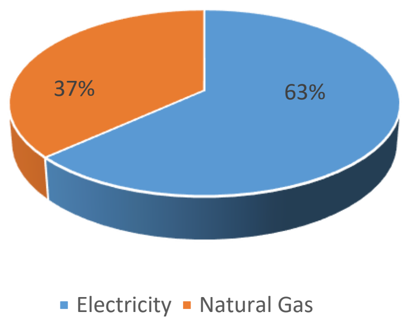

Figure 4-15:Cost breakdown on the basis of sources

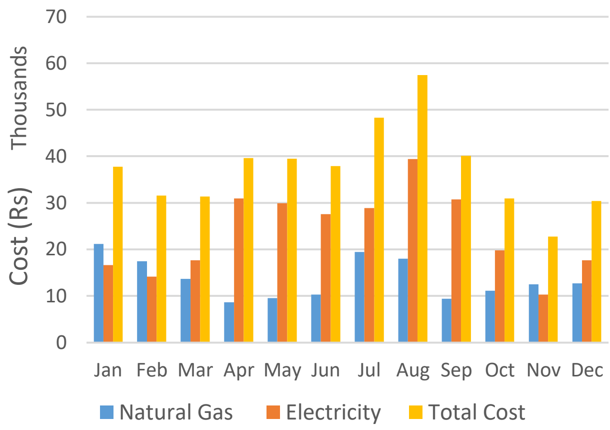

Figure 4-16:Total annual cost

4.1.2.5 Audit of the School-2

Survey of the school shows that its main load is because of fans and lights.

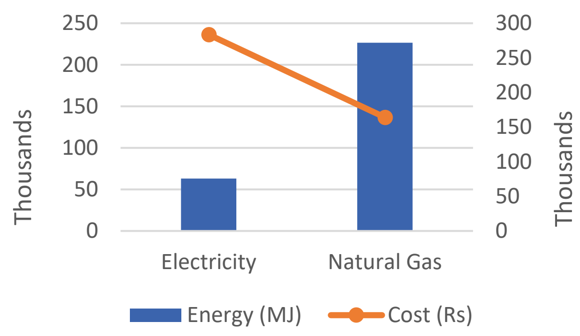

Figure 4-17:Comparison between cost and energy

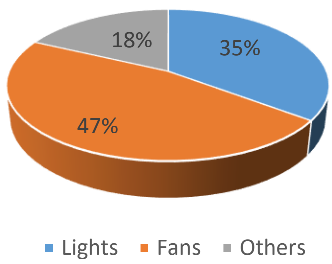

Figure 4-18:Load distribution of the School-2

4.1.2.6 PV System

Photovoltaic system was designed according to full rooftop capacity considering shading effect of the trees. 115kW system with 522 panels facing south can be seen in figure 4-19. Annual production of the system is 180.3MWh. Comparison of monthly production of the designed system with monthly electricity and natural gas consumption shows that school's energy requirements can be easily fulfilled, and plenty of energy is available for export to the grid.

Figure 4-19: Helioscope design of PV System for School-2

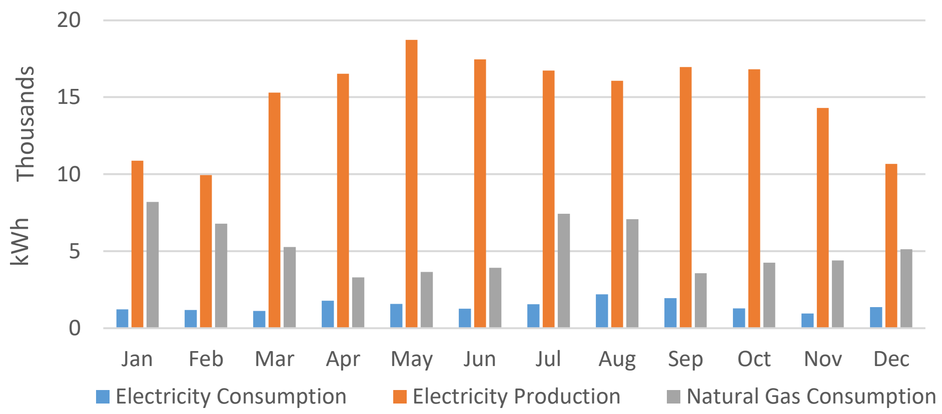

Figure 4-20: Comparison between annual energy consumption and production

4.1.2.7 Financial Analysis of PV system

Table 4-3: Financial analysis of PV system for School-2

PV System Capacity	120kW
Total No of Solar Panels(325W)	356
Cost of Solar Panels	6,942,000Rs
Number of Inverters(25kW)	6
Cost of Inverters	2,400,000 Rs
Other Accessories	1,095,450 Rs
Total Cost of the System	10,437,450 Rs
Payback Period	3-4 years

4.1.2.8 Net Zero Energy

School-2 total annual energy consumption is 289,751MJ, or 80.53MWh and its generation potential is 180.3MWh. School has the capacity to produce 99.77MWh more energy than its requirement. So, School-2 can easily achieve the net zero energy target.

Table 4-4:Net zero energy calculations for School-2

TYPE	Delivered	Exported	Net Zero
Net zero site energy	80.53MWh	180.3MWh	-99.77MWh
Net zero source energy	123.83MWh	568.09MWh	-444.26MWh
Net zero energy cost	447646Rs	2,344,514.9Rs	-1,896,868Rs
Net zero emissions energy	20997.68Kg	85304.27Kg	-64306.59Kg

4.1.3 Assessment of Net Zero Energy Potential of School-3

4.1.3.1 Annual Electricity Consumption

Total energy consumption of 21251 kWh was calculated. Electricity consumption peak can be observed in the month of September i.e. 2634 kWh followed by 2696 kWh in August whereas minimum was in February 932 kWh because of cold weather. Moreover, in the month of June and July in spite of the fact that school is closed for vacations, still electricity consumption is high.

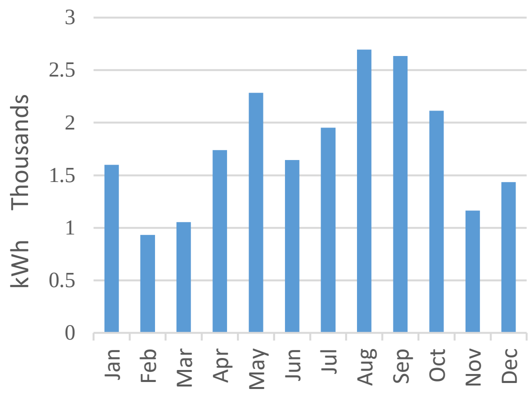

Figure 4-21. Annual electricity consumption

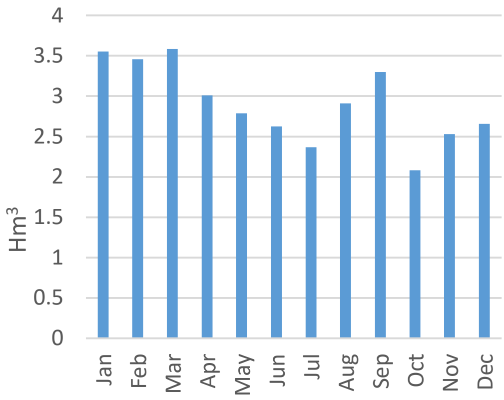

Figure 4-22. Annual gas consumption

4.1.3.2 Annual Gas Consumption

Total annual consumption of 34.866 Hm^3 was calculated. Gas consumption peak can be observed in the month of January, February, March i.e. 3.554, 3.458, 3.586 Hm^3 respectively whereas unusual peaks in August 2.91 Hm^3 and September 3.298 Hm^3 were observed.

4.1.3.3 Total Energy Consumption

Like other public school's energy consumption is once again dominated by natural gas in School-3. Maximum energy consumption can be seen in the month of September followed by August. In September consumption of both electricity and gas was at peak.

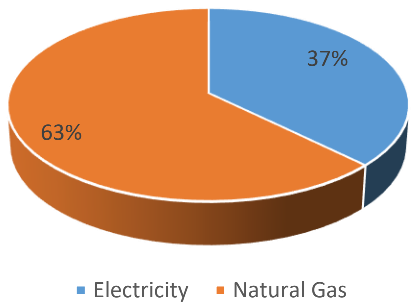

Figure 4-23:Breakdown on the basis of energy sources

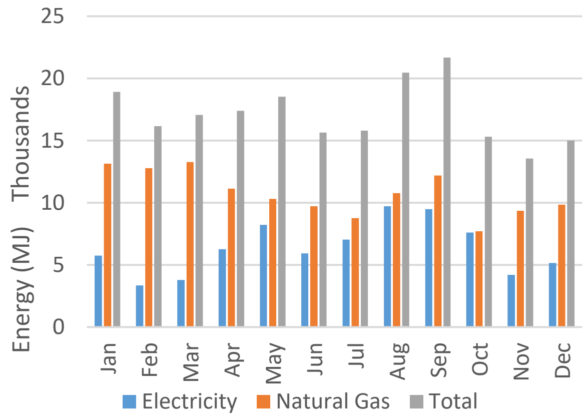

Figure 4-24:Total annual energy consumption

4.1.3.4 Cost Analysis

Electricity contributes to 82% of the total annual cost with 425417 Rupees. In figure, it is shown that natural gas contributes only 93531.42 Rs to annual cost and its annual energy contribution is more than its cost. Monthly cost analysis shows maximum cost in the month of May and minimum in February.

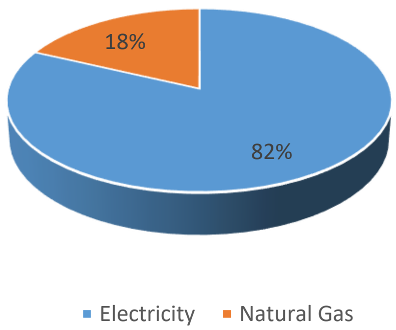

Figure 4-25:Cost breakdown on the basis of sources

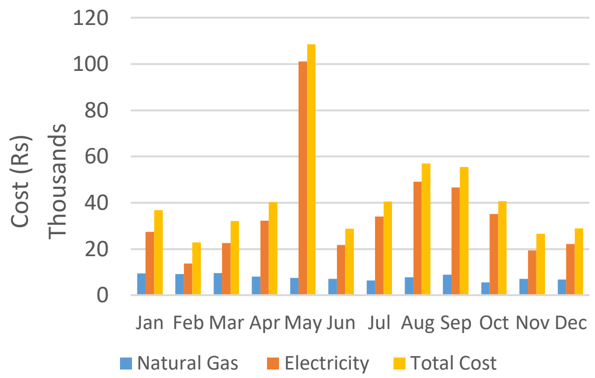

Figure 4-26:Total annual cost

4.1.3.5 Audit of the School

Survey of the school shows that its main load is because of fans and lights.

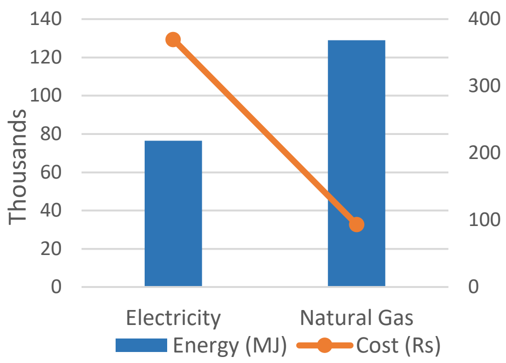

Figure 4-27:Comparison between cost and energy

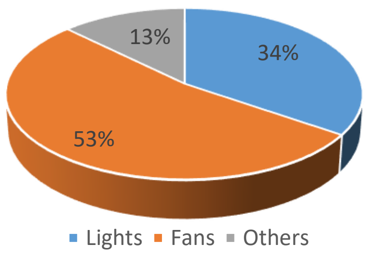

Figure 4-28:Load distribution of School-3

4.1.3.6 PV System

Photovoltaic system of capacity 169.7 kW system with 522 mono c-Si panels facing south was designed. Annual production of the system is 267.6 MWh. It is clear that school's energy requirements can be easily fulfilled, and ample amount of energy is available for export to the grid

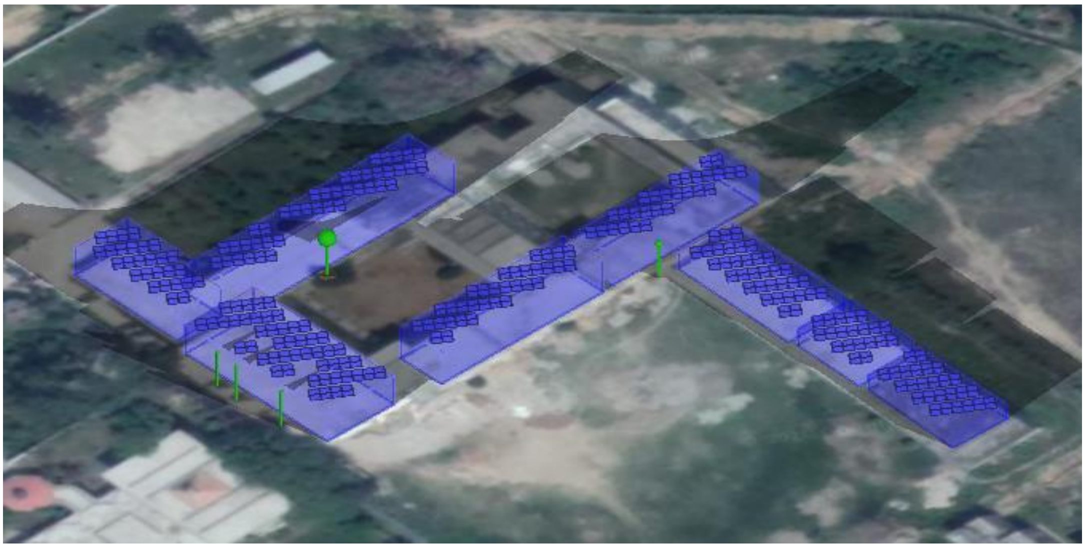

Figure 4-29:Helioscope photovoltaic system design for School-3

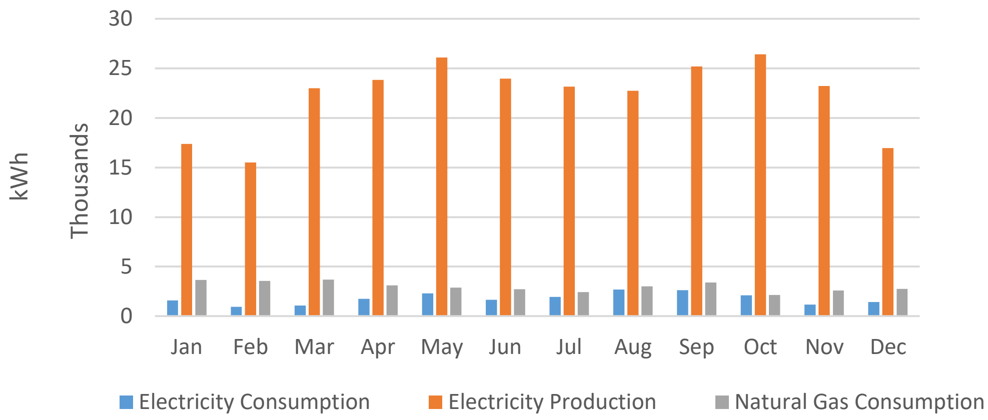

Figure 4-30: Comparison between annual energy consumption and production

4.1.3.7 Financial Analysis of PV system

Table 4-5: Financial analysis of PV system for School-3

PV System Capacity	180kW
Total No of Solar Panels(325W)	522
Cost of Solar Panels	10,179,000 Rs
Number of Inverters(60kW)	3
Cost of Inverters	40,50,000Rs
Other Accessories	2147500 Rs
Total Cost of the System	16,376,500 Rs
Payback Period	4-5 years

4.1.3.8 Net Zero Energy

School-3 total annual energy consumption is 205507.8 MJ, or 57.11MWh and its generation potential is 267.6MWh. School has the capacity to produce 210.4MWh more energy than its requirement. So, School-3 can easily achieve the net zero energy target. It can be observed from table 4-6 that all the values in net zero column are negative showing that School-3 can easily attain net zero energy.

Table 4-6:Net zero energy calculations for School-3

TYPE	Delivered	Exported	Net Zero
Net zero site energy	57.11MWh	267.6MWh	-210.49MWh
Net zero source energy	106.03MWh	871.27MWh	-765.24MWh
Net zero energy cost	518948Rs	2580613Rs	-2061665Rs
Net zero emissions energy	17288.85Kg	130828.54Kg	-113539.69Kg

4.1.4 Assessment of Net Zero Energy Potential of School-4

4.1.4.1 Annual Electricity Consumption

Total energy consumption of 14111 kWh was calculated. Electricity consumption peak can be observed in the month of September i.e. 1954 kWh followed by i.e.1499 kWh in August. Also, high consumption was observed in June i.e. 1016 kWh and July i.e. 1316 kWh whereas minimum was in Feb i.e. 652 kWh.

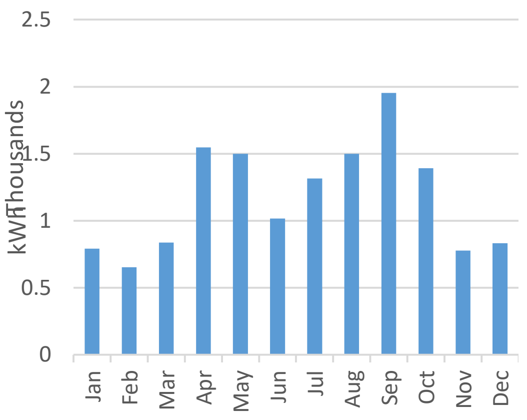

Figure 4-31. Annual electricity consumption

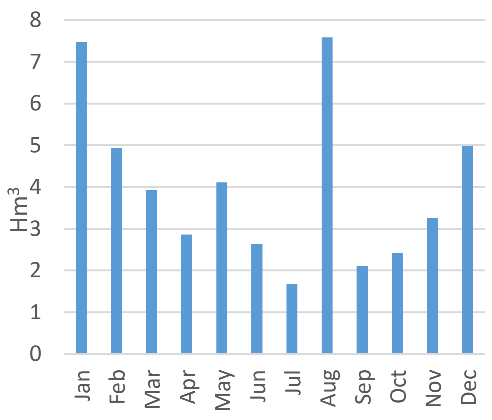

Figure 4-32. Annual gas consumption

4.1.4.2 Annual Gas Consumption

Total annual consumption of 47.979 Hm^3 was calculated. Gas consumption peak can be observed in the month of August i.e. 7.581 Hm^3 whereas unusual peak in May is observed.

4.1.4.3 Total Energy Consumption

Natural gas takes over electricity in terms of energy with 177522.3 MJ out of total 228,321.9 MJ. In figure 4-1 peaks in August and January can be observed due to high natural gas consumption during these months.

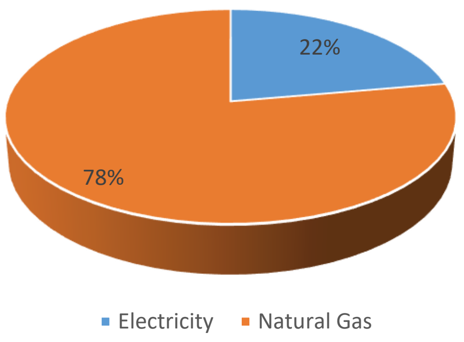

Figure 4-33:Annual energy consumption breakdown

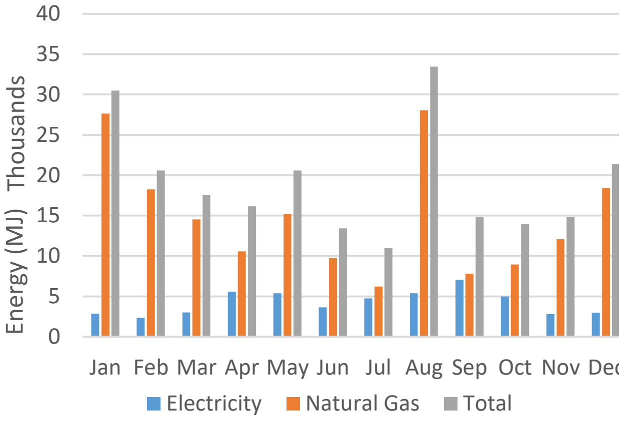

Figure 4-34:Total annual energy consumption

4.1.4.4 Cost Analysis

Electricity contributes to 66% of the total annual cost with 251262 Rupees. In figure 4-1 it is shown that natural gas contributes only 127963 Rs to annual cost and its annual energy contribution is more than its cost. Monthly cost analysis shows maximum cost in the month of August and minimum in June. Due to summer vacations lower consumption of electricity and natural gas leads to lower cost in June.

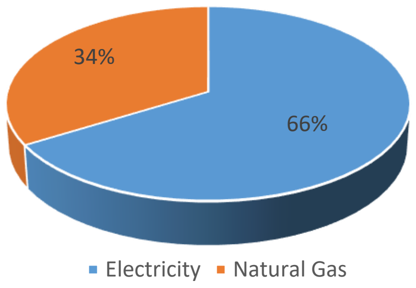

Figure 4-35:Cost breakdown on the basis of sources

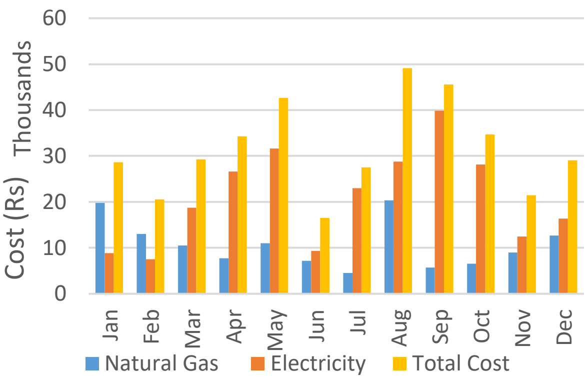

Figure 4-36:Total annual cost

4.1.4.5 Audit of the School

Audit results show that 97% of the total school load is due to the fans and lights.

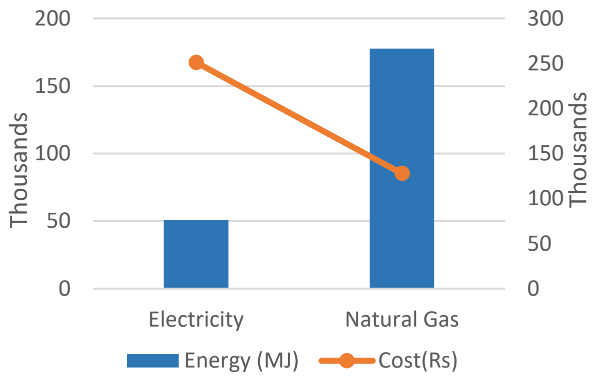

Figure 4-37:Comparison between cost and energy

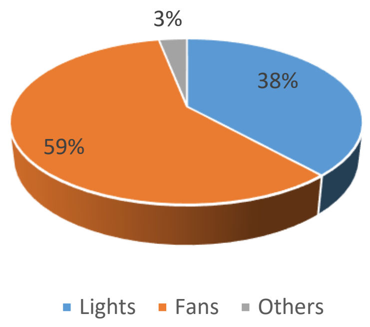

Figure 4-38:Load distribution of School-4

4.1.4.6 PV System

Photovoltaic system was designed according to full rooftop capacity considering shading effect of the trees. 76.7kW system using 236 panels, at tilt 33°, facing south was designed as shown in figure below. Annual production of the system is 120.6MWh. If we compare monthly production of the designed system with monthly electricity, then it is impossible to meet January requirements as natural gas consumption is 7680.5562 kWh and electricity consumption is 791kWh whereas total production in January is 7954 kWh. However, annual school's energy requirements can be easily fulfilled, and ample amount of energy is available for export to the grid.

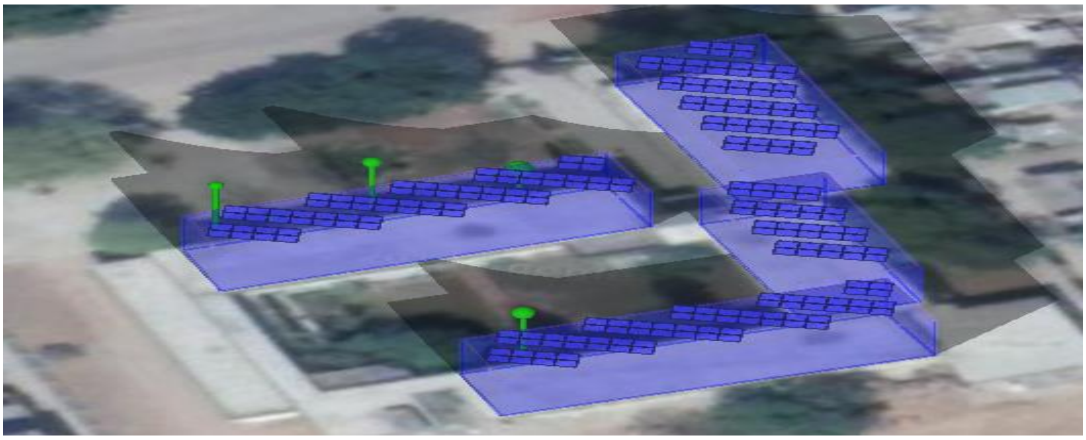

Figure 4-39: Helioscope PV system design of School-4

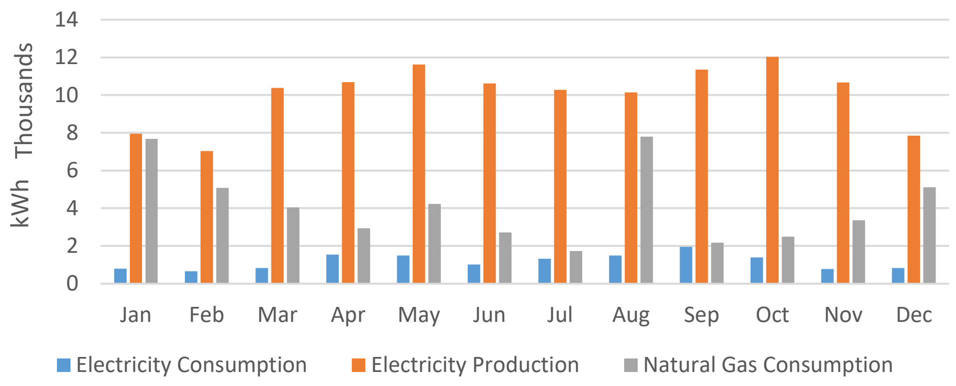

Figure 4-40:Comparison between energy consumption and generation

4.1.4.7 Financial Analysis of PV system

Cost of the PV system is calculated considering all the charges of accessories. Payback period was calculated.

Table 4-7: Financial analysis of PV system for school-4

PV System Capacity	80kW
Total No of Solar Panels(325W)	236
Cost of Solar Panels	4,602,000 Rs
Number of Inverters(20kW)	4
Cost of Inverters	1,600,000 Rs
Other Accessories	1,077,850 Rs
Total Cost of the System	7,279,850 Rs
Payback Period	3-4 years

4.1.4.8 Net Zero Energy

School-4 total annual energy consumption is 228,321.9 MJ or 63.46MWh and its generation potential is 120.6MWh. School has the capacity to produce 57.14MWh more energy than its requirement. So, School-4 can easily achieve the net zero energy target. Table 4-8 shows that School-4 can easily achieve net zero status.

Table 4-8:Net zero energy calculations for School-4

TYPE	Delivered	Exported	Net Zero
Net zero site energy	63.46MWh	120.6MWh	-57.14MWh
Net zero source energy	152.04MWh	379.98MWh	-227.94MWh
Net zero energy cost	379225Rs	1568155Rs	-1188930Rs
Net zero emissions energy	26593 Kg	57057 Kg	-30464Kg

4.1.5 Assessment of Net Zero Energy Potential of School-5

4.1.5.1 Annual Electricity Consumption

Total energy consumption of 9547 kWh was calculated. Electricity consumption peak can be observed in the month of August i.e. 1387 kWh. whereas unusual peak was in June i.e. 770 kWh and July i.e. 990 kWh were observed.

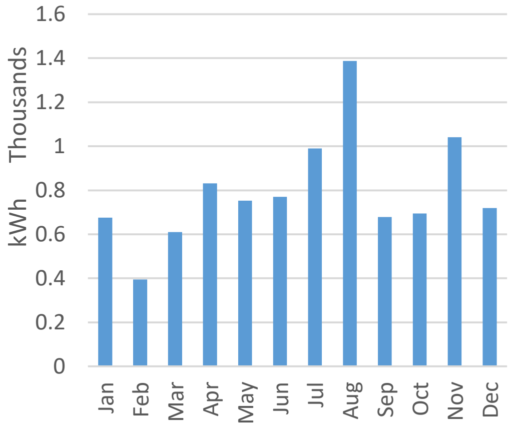

Figure 4-41. Annual electricity consumption

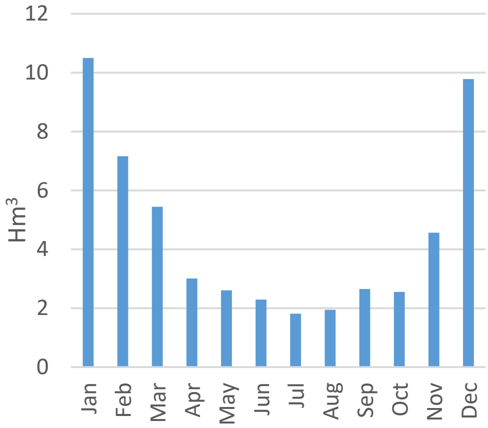

Figure 4-42. Annual natural gas consumption

4.1.5.2 Annual Gas Consumption

Total annual consumption of 54.342Hm^3 was calculated. Natural gas consumption follows predicted trend. its consumption start increasing in November and reach peak in January and then gradually decrease. Gas consumption peak can be observed in the month of January i.e. 10.495Hm^3. December and January show high consumption because of winters.

4.1.5.3 Total Energy Consumption

Natural gas takes over electricity in terms of energy with 201065.4 MJ out of total 235434.6 MJ or 65.44MWh. In figure peaks in December and January can be observed due to high natural gas consumption during these months.

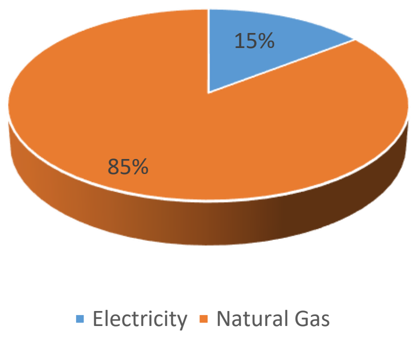

Figure 4-43:Energy breakdown on the basis of sources

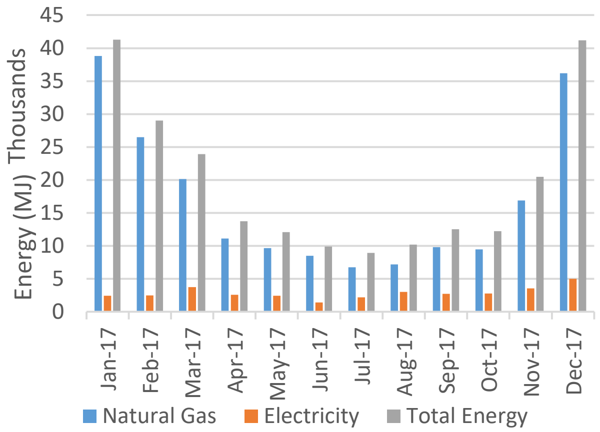

Figure 4-44:Total annual energy consumption

4.1.5.4 Cost Analysis

In figure, it is shown that both natural gas and electricity contributes equally in total cost. Electricity contributes to 51% of the total annual cost with 139190 Rupees whereas natural contributes to 49% of the total annual cost with Rupees 143966. Monthly cost analysis shows maximum cost in the month of January and December and minimum in June. Maximum cost in the month of January because of 27000 natural gas bill.

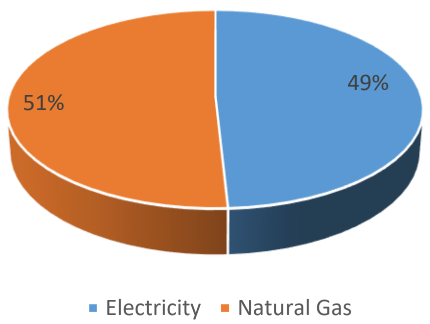

Figure 4-45:Cost breakdown on the basis of sources

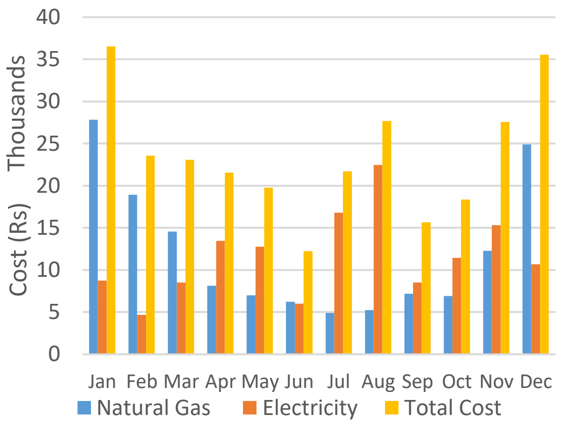

Figure 4-46:Total annual cost

4.1.5.5 Audit of the School

Audit results show that 94% of the total school load is due to the fans and lights.

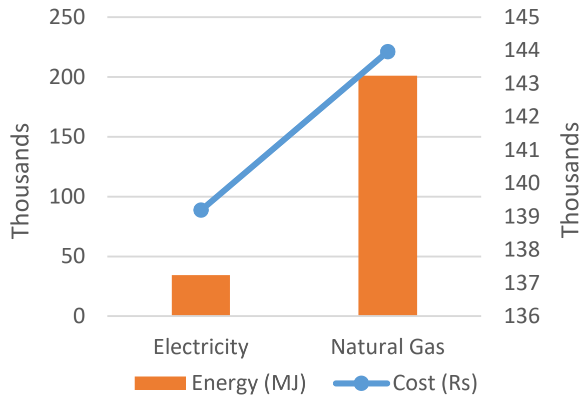

Figure 4-47: Comparison between energy and cost for school-5

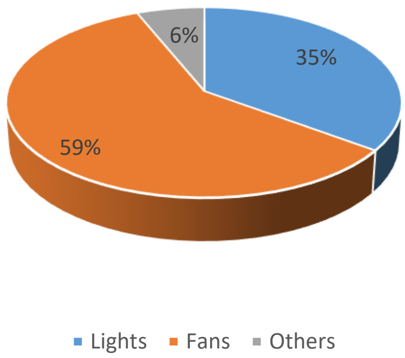

Figure 4-48:Load distribution of School-5

4.1.5.6 PV System

Photovoltaic system was designed according to full rooftop capacity considering shading effect of the trees. 148.5kW system using 408 panels, at tilt 30°, facing south was designed as shown in figure below. Annual production of the system is 235MWh. If we compare monthly production of the designed system with monthly electricity, it clearly shows that energy requirements can be easily fulfilled, and ample amount of energy is available for export to the grid.

Figure 4-49: Helioscope PV system design for School-5

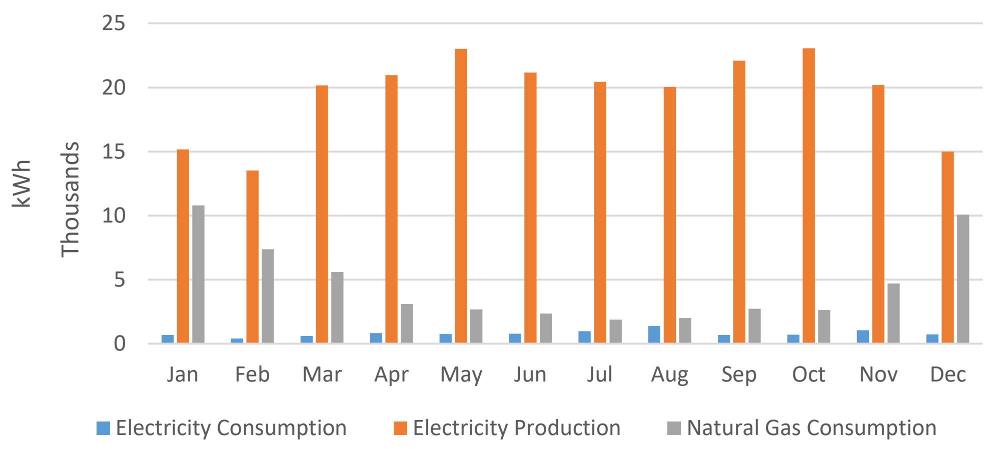

Figure 4-50: Comparison between annual energy consumption and production for school-5

4.1.5.7 Financial Analysis of PV system

Cost of the PV system is calculated considering all the charges of accessories. Payback period was calculated.

Table 4-9: Financial analysis of PV system for School-5

PV System Capacity	150kW
Total No of Solar Panels(325W)	457
Cost of Solar Panels	8,911,500 Rs
Number of Inverters(25kW)	3
Cost of Inverters	3,300,000 Rs
Other Accessories	1,904,500 Rs
Total Cost of the System	14,116,000Rs
Payback Period	5-6 years

4.1.5.8 Net Zero Energy

Table 4-10 shows that School-5 can easily achieve net zero energy target.

Table 4-10:Net zero energy calculations for School-4

TYPE	Delivered	Exported	Net Zero
Net zero site energy	65.44MWh	169.56MWh	-104.12MWh
Net zero source energy	90.999MWh	739.68MWh	-648.68MWh
Net zero energy cost	283156Rs	2183807Rs	-1900651Rs
Net zero emissions energy	15795.19 Kg	111068.91Kg	-95273.72Kg

4.1.6 Comparison Among Public Schools

In graph in the figure 4-51 comparison of 5 public school's electricity consumption, natural gas consumption, electricity cost and natural gas cost is shown. All schools have high natural gas consumption as compared to electricity and electricity leads the natural gas in terms of cost. Cost peak of electricity consumption can be observed for School-3 which has the highest electricity consumption among all schools.

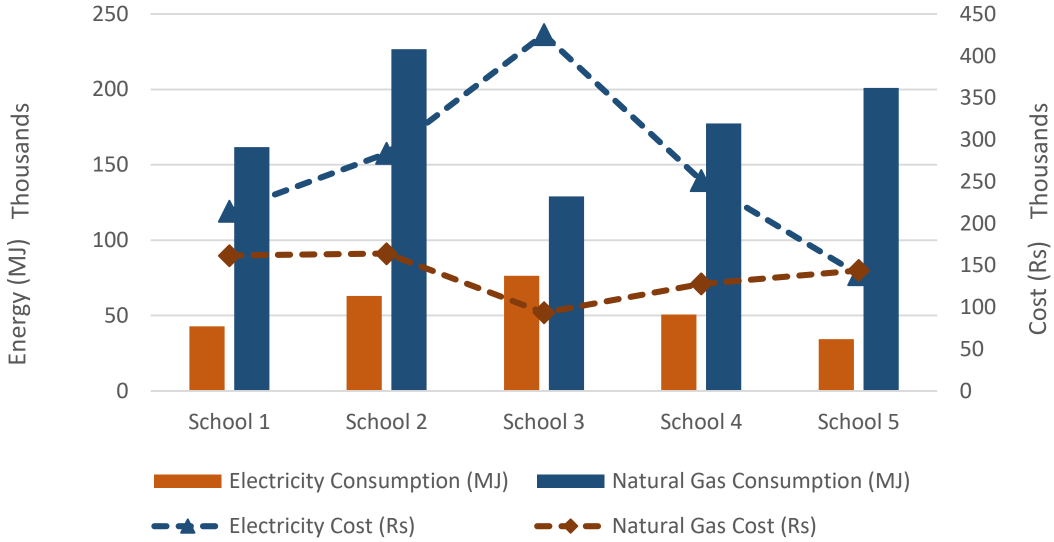

Figure 4-51:Comparison among all public schools

4.2 Private Schools

Two private school buildings were selected and analyzed for Net Zero Energy Potential assessment.

4.2.1 Private School-1

Private School-1 is a purpose built building.

4.2.1.1 Annual Electricity Consumption

The total energy consumption of 99840 kWh was calculated from electricity bills of one year. In our study we considered the cooling requirements for the months of April to October and heating for December to February and in March and November weather is mild. From the graph in the figure 4-52 it can be seen that energy consumption from April to October is maximum and is at its peak in the month of August i.e. 19040 kWh due to increased cooling load as it is summer and minimum consumption i.e. 2720 kWh was observed in February. The school is forced to use air conditioners throughout the school timings to maintain thermal comfort. But on contrary in the month of June and July consumption is quite low, the reason behind low consumption is summer vacations in the school. It can be observed that electricity consumption in winters is also very low as it is mostly used for lightning purpose and in few class rooms for heating purpose which have inverter AC.

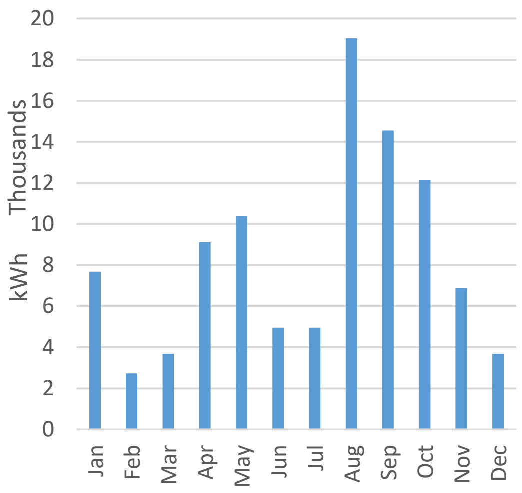

Figure 4-52. Annual electrical consumption

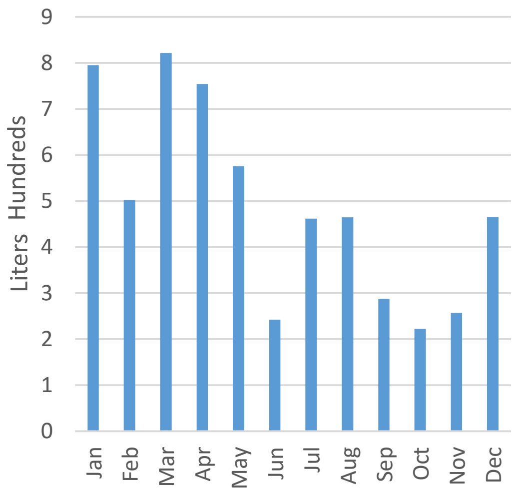

Figure 4-53. Annual fuel consumption

4.2.1.2 Annual Fuel Consumption

The school has onsite 98KVA backup generator which provides power when the grid power is not available. Data for the fuel consumption of the generator was collected for the whole year. The city is facing an unpredictable schedule of power outages throughout the year. And this is the reason the consumption data of fuel does not show specific pattern which can be observed from the figure 4-53.

4.2.1.3 Annual Gas Consumption

Natural gas is used for cooking in the kitchen and cafe and also for gas powered heaters in class rooms and offices which are only used in winter season. School has three natural gas connections named as Meter 1, Meter 2 and Meter 3. It can be seen from the graphs in the figure 50 that gas consumption is gradually increasing from November and is at its maximum 38.743Hm^3 in January. Meter3 which is used for cooking in the café shows unusual consumption behavior in the month of June and July.

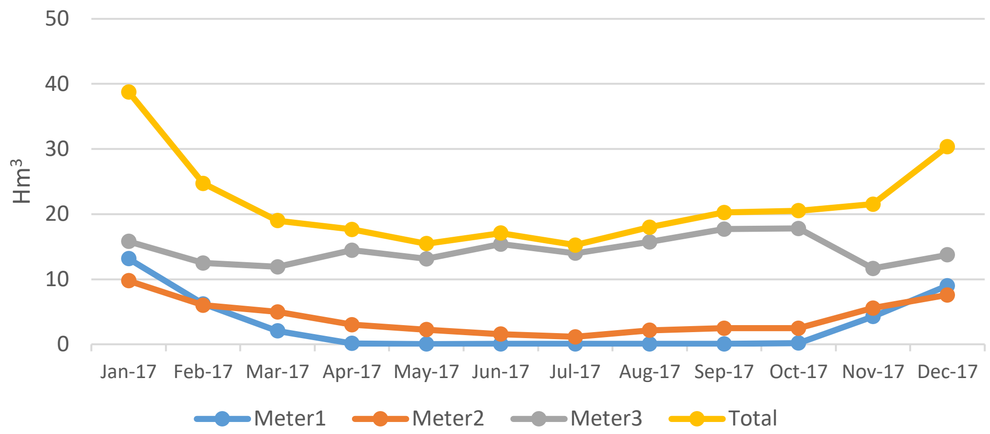

Figure 4-54:Annual natural gas consumption

4.2.1.4 Total Energy Consumption

Total annual energy consumption 1494081.504 MJ or 415.35MWh was calculated. The total energy mix shows that electricity contributes 24%, natural gas 64% and fuel 14% to the total energy consumption. In summers electricity is the dominant energy consumption source due to the extensive use of air conditioners while in winters natural gas dominates and gas heaters are the major source of gas consumption. The overall peak energy consumption of the school was observed in the month of January at 198.7MJ. Analysis show that building natural gas system is improperly maintained and in literature review it was also found that building mechanical systems were improperly maintained and operated[3].

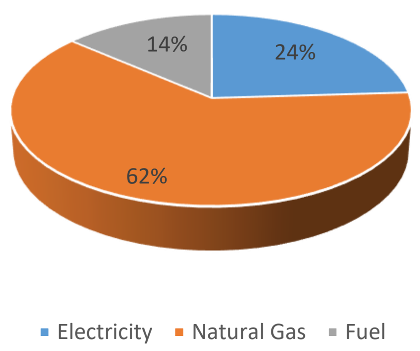

Figure 4-55:Energy breakdown on the basis of sources

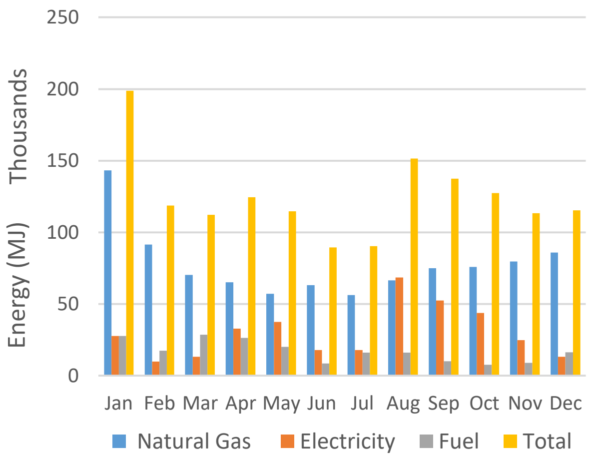

Figure 4-56:Total Annual Energy

4.2.1.5 Cost Analysis

If we analyze the energy consumption in terms of cost, we see that electricity is the dominant factor as it is quite expensive in our country. From the figure 4-57 it is clear that we have an opportunity to reduce the cost to a great extent if we reduce electricity consumption.

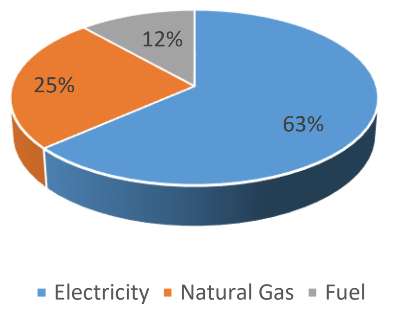

Figure 4-57:Cost breakdown on the basis of sources

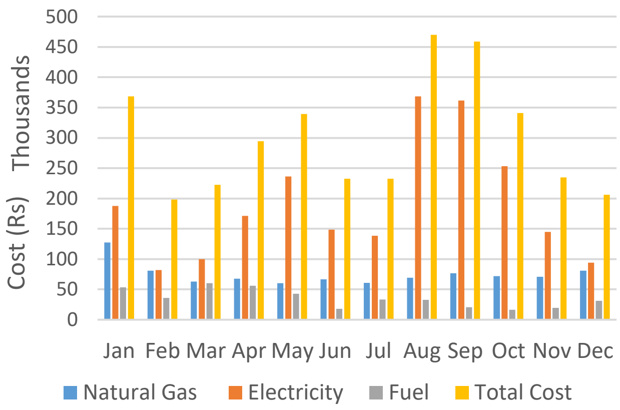

Figure 4-58:Total annual cost

4.2.1.6 Audit of the School

It was found through ASHRAE Level 1(Walk Through) audit among electrical appliances 90% of the load is due to air conditioners and classrooms contributed towards most of the school load and this is the reason that classrooms load distribution is considered for energy efficiency measures. Figure4-61 shows the total load distribution of the class rooms. Among the different types of loads 74% of the load was cooling load because of the air conditioners. The reason behind high cooling load is the use of conventional type split air conditioners which are not energy efficient and also not environmental friendly. On site only 21 percent of the classrooms have DC inverter air conditioners which are energy efficient.

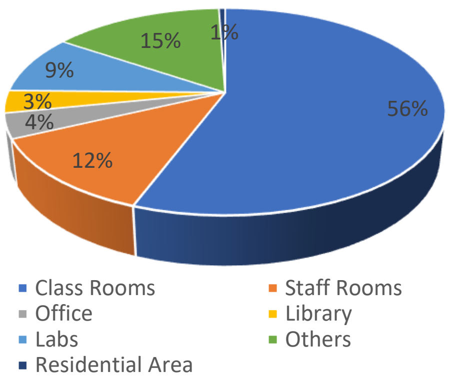

Figure 4-59:Load distribution by space type

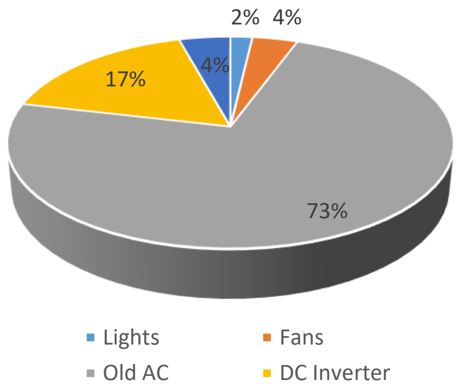

Figure 4-60:Load distribution by appliances type

A comparative study has been done to show the improvements through replacement of appliances from conventional to energy efficient appliances. It was concluded that lighting load can be reduced up to 64% by replacing the existing lights with LED and fan load up to 58% replacing them with energy saver fans and air conditioners up to 39% just by replacing them with DC inverter air conditioners.

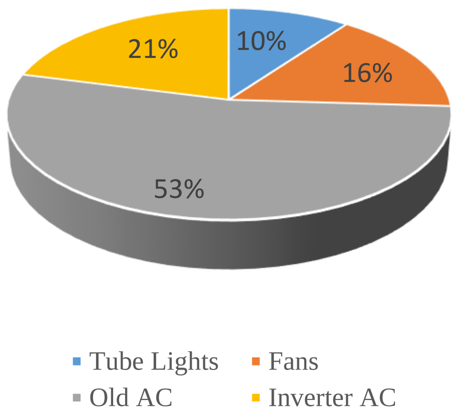

Figure 4-61:Class rooms load distribution

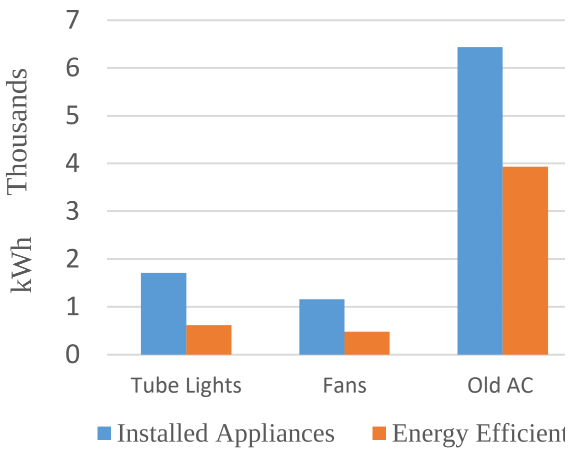

Figure 4-62:Comparison between conventional and energy efficient appliances

4.2.1.7 Financial Analysis of Energy Efficient Appliances

Economic analysis of retrofitting measures is an important factor in decision making[1]. Financial analysis of the energy efficient appliances shows that changing old appliances will cost a lot more and their payback period is very large for fans and air conditioners.

Table 4-11: Financial analysis of energy efficient appliances

	Lights	Fans	Air Conditioner
Total Cost of replacing all of them	306,000Rs	988,000Rs	3,139,600Rs
Total Cost of replacing only in class rooms	166,500Rs	467,200Rs	1,561,100Rs
Payback period for replacing all of them	3 years	17.6 years	14 years
Payback period for replacing only in class rooms	3 years	18 years	13 years

4.2.1.8 PV System

PV system of 123.5 kW was designed with 380 modules of 325 watts each using Helioscope. Annual production capacity of the system is 196.7MWh. If we compare monthly production with consumption in the month of August consumption exceeds production by 1917kWh.

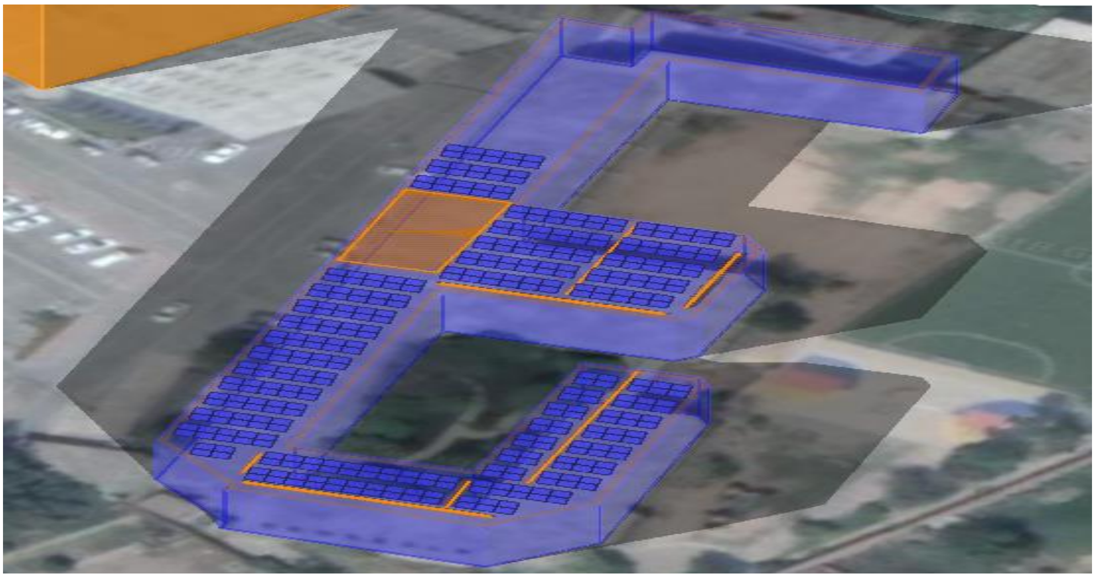

Figure 4-63:PV system design for Private School-1 on Helioscope

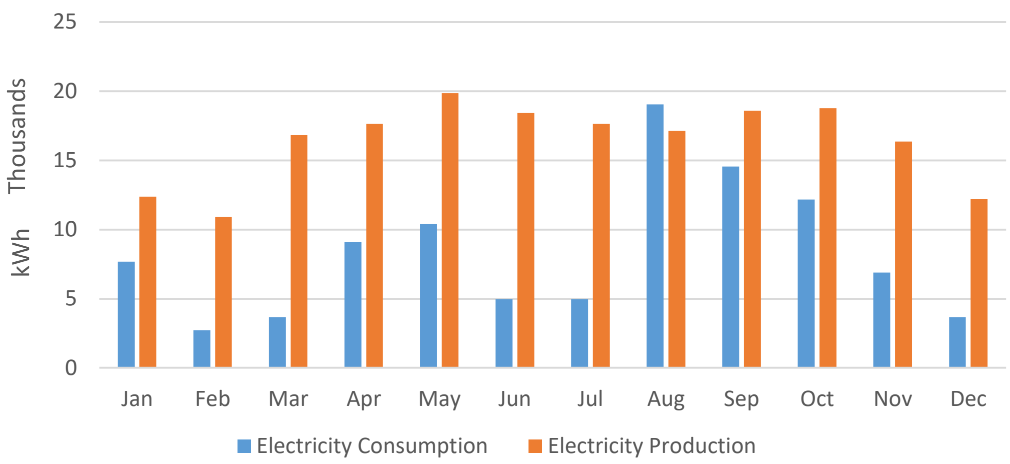

Figure 4-64: Comparison between annual energy consumption and production for Private School-1

4.2.1.9 Financial Analysis of PV system

Table 4-12: Financial analysis of PV system for Private School-1

PV System Capacity	125kW
Total No of Solar Panels(325W)	380
Cost of Solar Panels	7,410,000 Rs
Number of Inverters(25kW)	5
Cost of Inverters	2,250,000 Rs
Other Accessories	1,401,900 Rs
Total Cost of the System	11,062,250 Rs
Payback Period	4-5 years

4.2.1.10 Net Zero Energy

School has an annual energy consumption of 415.35MWh and production capacity of 196.7MWh which is a lot lesser than the energy requirements of the school building. It is not possible to make this school net zero because of high natural gas consumption.

Table 4-13:Net zero energy calculations for Private School-1

TYPE	Delivered	Exported	Net Zero
Net zero site energy	415.35MWh	196.7MWh	218.65MWh
Net zero source energy	663.95MWh	619.52MWh	44.43MWh
Net zero energy cost	3598673Rs	1829071Rs	1769602Rs
Net zero emissions energy	120859.23Kg	93026.94Kg	27832.29Kg

4.2.2 Private School-2

Private School-2 is house based school building comprised of three houses.

4.2.2.1 Annual Electrical Consumption

Total annual electricity consumption of 9344kWh was calculated. School shows peak consumption in September of 1433kWh because of fans use. In June and July electricity consumption can be observed figure 4-65, it's because school is used as an academy during summer vacations. Annual approximate consumption of fuel for generators is 16264kWh and total annual energy consumption is 25608kWh.

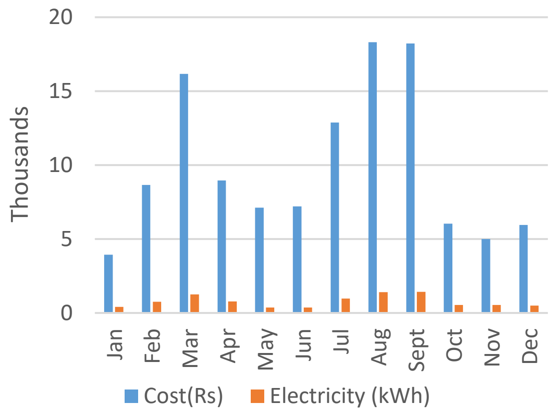

Figure 4-65:Annual electricity consumption and cost

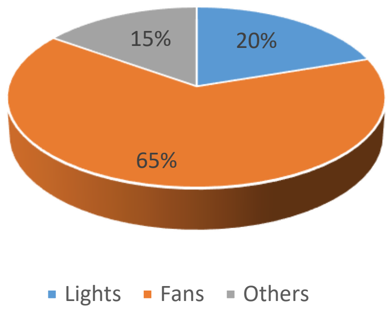

Figure 4-66:Load distribution of school

4.2.2.2 Cost Analysis

As school use only electricity for fulfilling its energy requirements and occasionally generators in case of load shedding. Total annual cost of electricity is 118450 rupees and annual fuel cost is approximately 110,000 rupees.

4.2.2.3 Audit of the School

School building comprised of three house buildings and 65% of its load is due to fans which are not energy efficient and 20% is of lights. Lights installed are mainly energy savers and LED lights.

4.2.2.4 PV System

Photovoltaic system of 18.2kW was designed consisting of 58 mono c-silicon modules of 325watts. Annual production capacity of system is 28.27MWh.

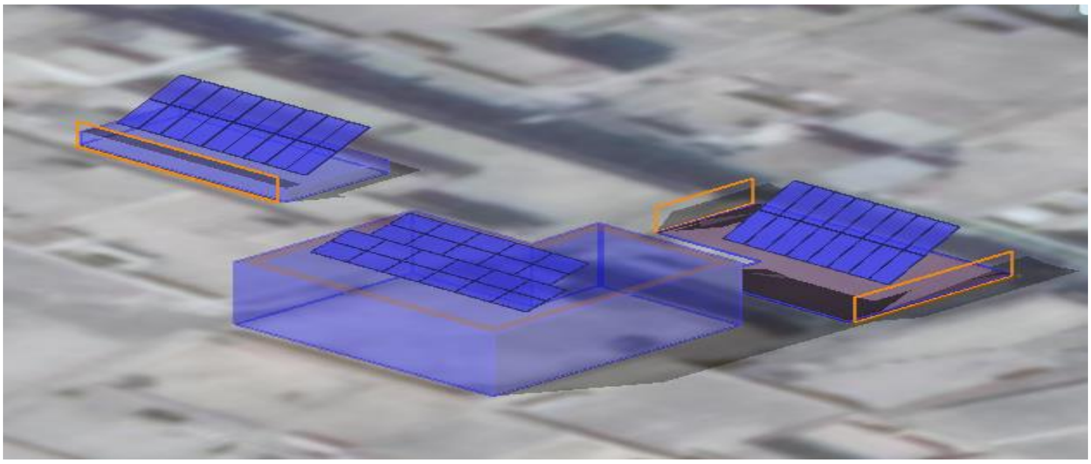

Figure 4-67: PV system for Private School-2 on Helioscope

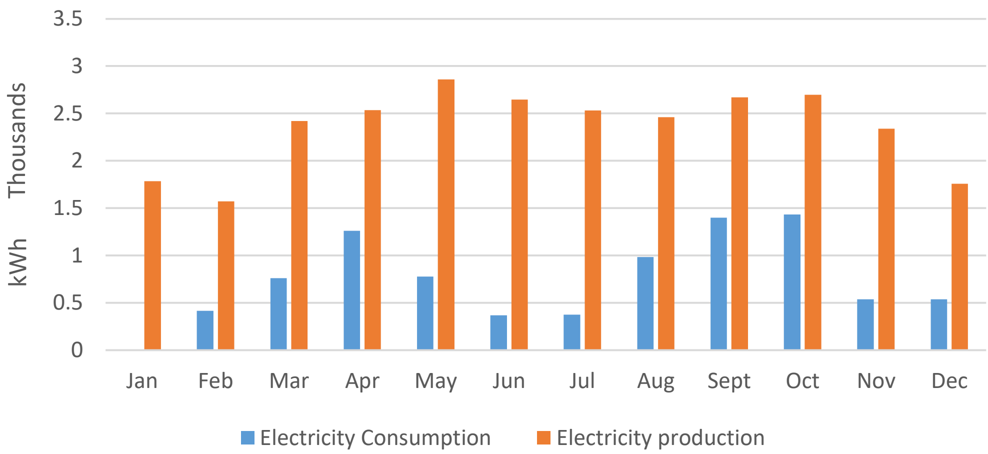

Figure 4 68:Comparison between electricity consumption and production

4.2.2.5 Financial Analysis of PV system

Table 4-14:Financial analysis of efficient fans

Financial Analysis	Fans
Total No of Fans	49
Total Cost	168,000Rs
Payback period	6.84 years

Table 4-15: Financial analysis of PV System for School-2

PV System Capacity	18.8kW
Total No of Solar Panels(325W)	57
Cost of Solar Panels	1,225,250 Rs
Number of Inverters(9.4kW)	2
Cost of Inverters	600,000 Rs
Other Accessories	359,850 Rs
Total Cost of the System	2,163,975 Rs
Payback Period	5-6 years

4.2.2.6 Net Zero Energy

Total annual energy consumption is 25.6MWh and annual production capacity of 28.27MWh. This school can become net positive with 2.67MWh extra energy and from table 4-15 it can be seen that school can attain targets of all types of net zero energy.

Table 4-16: Net zero energy calculations for Private School-2

TYPE	Delivered	Exported	Net Zero
Net zero site energy	25.6MWh	28.27MWh	-2.67MWh
Net zero source energy	47.18MWh	89.06MWh	-41.88MWh
Net zero energy cost	228450Rs	262929Rs	-34479Rs
Net zero emissions energy	8144.88Kg	13372.66Kg	-5227.78Kg

4.3 Energy Utilization Index

Energy utilization index is the energy usage per square meter of a building and it allow us to compare different size buildings. Median EUI for United States is 48.5 kBtu/ft^2 and for Canada 750MJ/m^2 [4]. From table 4-16, it can be seen that all of the schools have very low EUI values as compared to United States and Canada. Maximum EUI is of the purpose built private school building because of the high natural gas consumption and use of air conditioners.

Table 4-17: Comparison of EUI of all school buildings

School	EUI (MJ/m^2)
Public School-1	110.64
Public School-2	83.17
Public School-3	31.88
Public School-4	70.16
Public School-5	111.13
Private School-1	259.72
Private School-2	20.18

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Chapter 5

Conclusion and Recommendations

Study of three different cases of school buildings public schools, purpose built private schools and house based private schools was carried out. Results show that in terms of cost, electricity plays major role while natural gas is the major contributor in annual energy consumption in schools. It is concluded from the analysis that implementation of energy conservation and efficiency measures payback is longer in case of school buildings due to their short working hours so they or not financially feasible.

In case of public school buildings as they were already retrofitted with efficient appliances and have huge rooftop area, their PV system design shows that they can easily achieve net zero site energy status on annual basis. Furthermore, net zero source energy, net zero energy cost and net zero energy emissions analysis also shows that because of low energy requirements and high onsite potential, these targets are easily attainable.

Analysis of purpose built private school building shows that despite having large rooftop area because of air conditioning load and high natural gas consumption it is not possible to attain net zero energy target. House based private school don’t have large rooftop area but still it is possible for it to attain net zero energy target because of no natural gas consumption.

It is also concluded that overall energy consumption is very low as compared to other countries.

Moreover, in future net zero energy analysis of the public school buildings considering their future air conditioning energy demands can be done. In addition, indoor environment quality and water efficiency along with energy consumption of different school buildings can be studied.

Appendix

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August 1-2, 2018, Lahore, Pakistan

Energy Consumption Profile of a K-12 School Building and Identification of Energy Conservation and Energy Efficiency Measures

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Abstract

The main objective of this research is to take a school building in Rawalpindi as a case study and investigate its annual energy consumption. This study has identified that electricity and natural gas are the main energy sources but due to power failures and unreliable supply from the national grid, the school is also dependent on a generator for power generation. It is concluded from the analysis that in terms of cost electricity dominates other sources. In Pakistan majority of the buildings are not energy efficient and hence require large amount of energy to meet their cooling and heating demands. This study also suggests energy conservation and energy efficiency measures for reducing the energy consumption of the building.

Keywords
K-12 Buildings, Energy Conservation, Energy Efficiency

1. Introduction

Energy is considered as basic need of humans now. World energy generation is dominated by oil and gas. These conventional sources are not only depleting at a fast pace but have also raised concern for global warming. Buildings consume 40% of the world energy consumption and accounts for one third of the greenhouse gas emissions (Lou, Tsang, Li, Lee, & Lam, 2017). According to the 2018 report, Pakistan has approximately a population of 200 million and 39.7% of the people live in urban area ("Pakistan Demographics Profile 2018," n.d.). In Pakistan 64.2% of the total electricity consumption in all sectors is from fossil fuel ("About Pakistan," n.d.), mostly buildings are poorly insulated and people are not aware of the energy efficiency measures in buildings. Due to the inadequate air tightness of occupied spaces, poor insulated roofs and walls, lack of energy efficiency practices, heating and cooling loads of the buildings in residential as well as commercial sectors are very high. Pakistan can save up to 1100MW in household and industrial sector just by energy efficiency measures ("Energy efficiency| The Express Tribune," n.d.).

Pakistan being the fifth most populated state in the world has large number of schools ("Population Of Pakistan " n.d.). Among buildings, educational buildings represent the highly visible model that can help diffuse innovation in the society. A lot of studies have been carried out worldwide regarding energy consumption of school buildings but no such study has been carried out in Pakistan. Public buildings like schools can play an exemplary role in relation to energy saving and are the perfect place for awareness and capacity building of the future generations (Dias Pereira, Raimondo, Corgnati, & Gameiro da Silva, 2014). This research was carried out to study the energy consumption of a typical school building in Rawalpindi. The objective of this research was to observe and analyze the energy consumption, load profile of the school and energy conservation opportunities in buildings.

2. Energy Consumption

The methodology used for this research was in such a way that a team of qualified and experienced energy engineers visited the school for a walk through energy audit. Institution is a two story building consisting of 36 Classrooms, 2 computer labs, 2 science labs, 6 store rooms, an art room, a music room, a library,a gym,a café and several staff offices. A detailed analysis was done by the team, relevant documents and energy bills were acquired already before the visit, on spot surveys and interviews were conducted from the teachers, staff, technical team and management team. The data related to appliances their number, power consumption,usage pattern and duration was collected.School building utilizes three different types of sources for fulfilling its energy requirements. Electricity from the grid is used for powering electrical equipments, lighting, computers and air conditioning, diesel powered generator of 98KVA is used in case of no power supply from the grid and natural gas is only used for cooking and heating purpose. In this study we analyzed the total energy consumption both on source and cost basis.

2.1 Electricity

The energy bills for the period of one year were analysed in detail and the total energy consumption was calculated. In our study we considered the cooling requirements for the months of April to October and heating for December to February and in March and November weather is mild. From the graph in the figure 1 it can be seen that energy consumption from April to October is maximum and is at its peak in the month of August due to increased cooling load as it is summer. The school is forced to use air conditioners throughout the school timings to maintain thermal comfort. But on contrary in the month of June and July consumption is quite low ,the reason behind low consumption is summer vacations in the school. It can be observed that electricity consumption in winters is also very low as it is mostly used for lightning purpose and in few class rooms for heating purpose which have inverter AC.

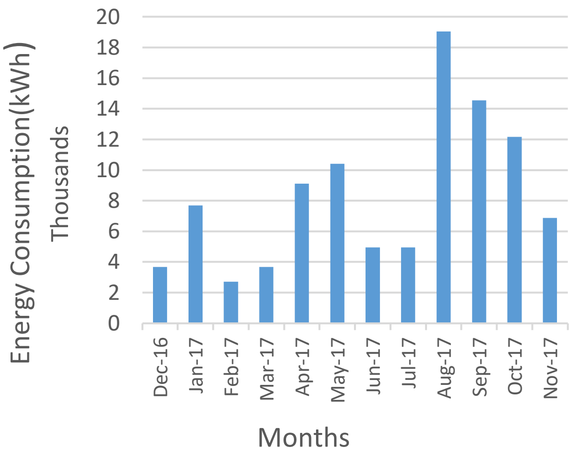

Figure 1: Annual energy consumption

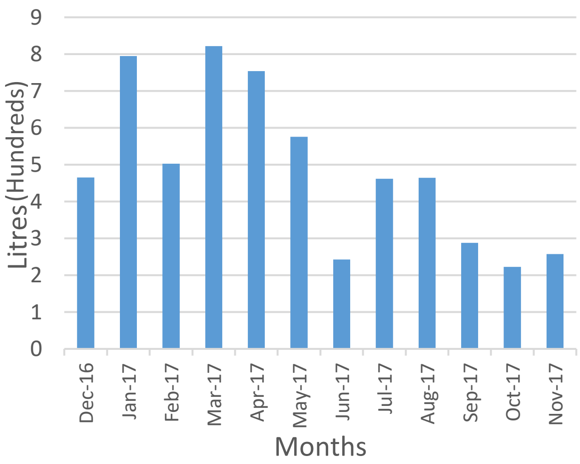

Figure 2: Annual fuel consumption

2.2 Generator

The school has onsite 98KVA backup generator which provides power when the grid power is not available. Data for the fuel consumption of the generator was collected for the whole year. The city is facing an unpredictable schedule of power outages throught the year. And this is the reason the consumption data of fuel does not show specific pattern which can be observed from the figure 2.

2.3 Natural Gas

Natural gas is used for cooking in the kitchen and also for gas powered heaters in class rooms and offices which are only used in winter season. School has two natural gas connections named as Meter 1 and Meter 2. It can be seen from the graphs in the figure 3 that gas consumption gradually increasing from November and is at its maximum in January. For the rest of the year gas consumption is almost constant as it is only being used for cooking purposes. Results shows that the gas consumption was minimum in the months of June and July due to summer holidays and kitchen is used only by the management team and security guards.

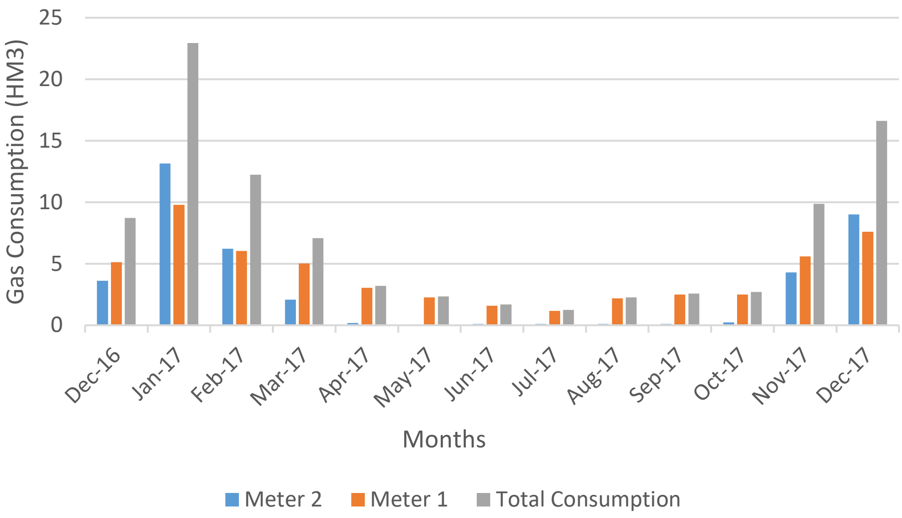

Figure 3: Annual natural gas consumption

2.4 Total Energy Consumption

The total energy mix shows that electricity contributes 42% of the energy. The school has on site commercial electricity meter installed and maintained by IESCO local distribution company. Natural gas contributes to 34% of the total energy consumption. The school has 2 on site natural gas meters installed by Sui Northern Gas Pipelines Limited. The school depends on diesel fuel for the generator which contributes to total energy mix by 24%. In summers electricity is the dominant energy consumption source due to the extensive use of air conditioners while in winters natural gas dominates and gas heaters are the major source of gas consumption. Electricity peak consumption of the school was observed in August, peak consumption of natural gas was observed in January. The overall peak energy consumption of the school was observed in the month of January at 140MJ.

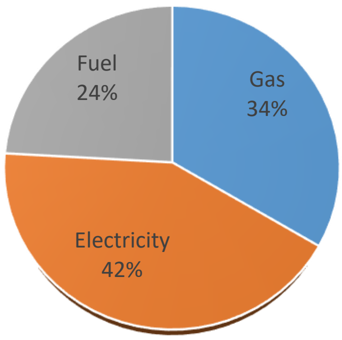

Figure 4: Energy consumption breakdown on the basis of sources

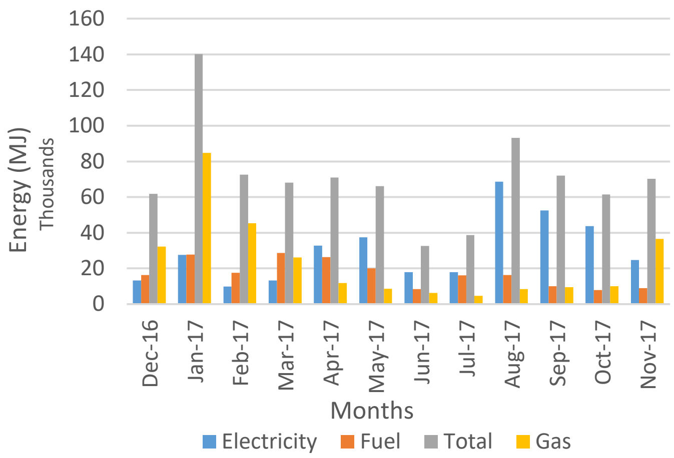

Figure 5: Total annual energy consumption

3. Energy Audit of the Building

ASHRAE Level 1(Walk Through) audit was conducted on site and it was found that classrooms contributed towards most of the school load and this is the reason in this article only the load profile of the classrooms is discussed. Every classroom has 6 tubelights, 4 local brand fans and an air conditioner. Among the different types of loads 75% of the load was cooling load because of the air conditioners. Tubelights contribute to 14 percent, air conditioners 75 percent and fans 11 percent of its load. The reason behind high cooling load is the use of conventional type split air conditioners which are not energy efficient and also not environmental friendly. On site only 21 percent of the classrooms have DC inverter air conditioners which are energy efficient. A comparative study has been done to show the improvements through replacement of appliances from conventional to energy efficient applicances. It was concluded that lighting load can be reduced upto 64% just by replacing the tube lights with energy efficient LED lights. Fan load can be reduced upto 39% by replacing old fans with energy efficient fans. If the conventional air conditioners are replaced with energy effcient ones then the cooling load can be reduced upto 39%.

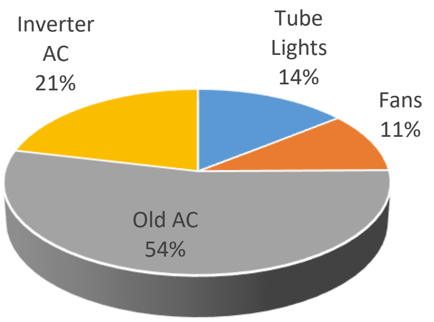

Figure 6: Load distribution of the class rooms

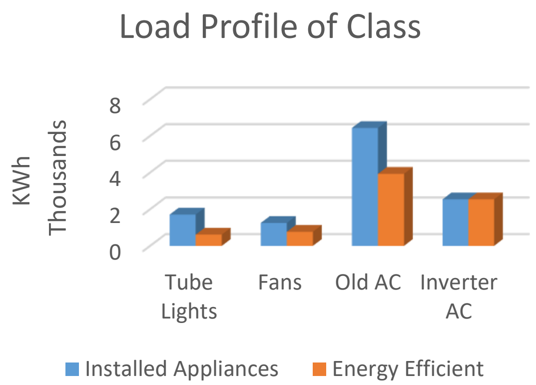

Figure 7: Comparison between the old and energy efficient appliances

4. Cost Analysis

If we analyze the energy consumption in terms of cost we see that electricity is the dominant factor as it is quite expensive in our country. From the figure 8 it is clear that we have an opportunity to reduce the cost to a great extent if we reduce electricity consumption.

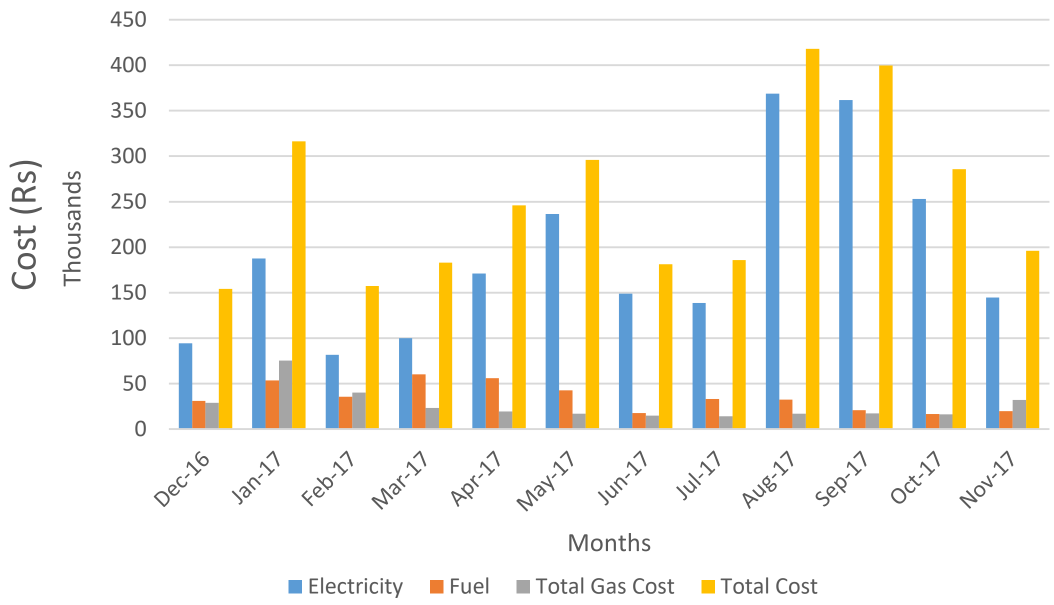

Figure 8: Cost analysis of all the energy sources

From the electricity bill ,it was observed that there are different tariffs for different number of units consumed and also fixed charges of Rs 400 per kW/M for load greater than 5kW. The tariff is Rs 9.25 for off-peak units consumed and Rs 15 for peak units. In figure 9 tariff breakdown for the month of January,2018 is shown and it can be seen that 37% of the total cost is due to the fixed charges of Rs 400 and 55% is due to Rs 9.25 and these values vary according to month.This concludes that if we implement energy conservation measures the cost of electricity can be greatly reduced not just by saving the number of units consumed but also its fixed charges.

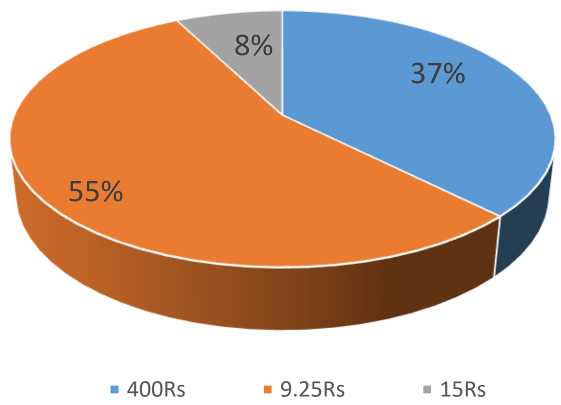

Figure 9: Tariff breakdown on the basis of cost for the month of January

5. Recommended Energy Conservation Measures

Beside replacing old electrical appliances with energy efficient appliances for reducing energy consumption various energy conservation measures can be taken like

- Installation of occupancy sensors to turn off the lights automatically when no one is present.
- Turning off the lights when daylight is available.
- Use of blinds and shades on windows in both summers and winters to prevent direct heat gain or loss.
- Installation of insulation on the roof top and reflective roof coating to reduce energy consumption.
- Plugging air leaks and keeping door close can also help avoid loss of heated or cooled air.
- For efficient operation regular maintenance of the heating and cooling equipment should be performed.
- Installation of solar PV rooftop systems can greatly reduce the energy costs.
- Plantation should be done in front of the walls of the buildings to provide shading to the building to keep it cool during summers.
- Procurement plan should be revised to procure ENERGY STAR rated products in the future.
- Awareness campaigns regarding energy conservation should be started in school to spread awareness among students, faculty and management.

6. Conclusion

This research article concludes that in Pakistan, educational sector is highly effected by loadshedding and unreliable source of energy. The educational sector is mostly dependant on national grid and partially depends on fossil fuel to run generators. In Pakistan the energy price increases with increase in consumption and this badly effects the school financial situation. It has also been observed that there is less awareness of energy efficiency and conservation in Pakistan and energy can be saved through energy conservation measures and energy efficient appliances. This research article also concludes that there is no trend of adopting renewable energy like solar PV in schools which is the best solution depending on the school timings and the cost of energy can be reduced by a significant amount by adopting solar PV technology on rooftop. Furthermore in future design and analysis of the PV system for the school building will be performed.

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