J. Engg. and Appl. Sci. Vol.38 No,2 July-December 2019 ISSN 1023-862X - eISSN 2518-4571

# MITIGATING $CO_2$ EMISSIONS OF ACADEMIC BUILDINGS IN PAKISTAN USING ENERGY CONSERVATION TECHNIQUES

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## ABSTRACT

*Energy use data of the sample school was gathered from available records as well as measured using an in-house developed metering device that recorded the electric consumption data on hourly bases. Building energy simulations were also carried out using TRNSYS© software for validating and comparing the actual energy consumed and optimal energy consumption resulting from building energy simulation of the existing and re-designed building. The results highlighted that if the building had been designed with proper considerations for energy efficiency, up to 30% of energy could have been saved. The measurements and analysis indicated that other measures like the use of different types of window glazing, LED Lighting, efficient gas heating, and improvement in behavior pattern could also result in substantial energy savings. The maximum achievable savings can be as much as 50% of the energy cost of the school buildings. Additionally, once extrapolated over the entire school-going population of Pakistan the $CO_2$ emission savings come out to be substantial, amounting to 3.07 M tonnes annually.*

**KEYWORDS:** Building energy simulation; built environment; carbon emissions; energy conservation

## INTRODUCTION

A huge amount of available energy is being used by the built environment in developing countries. The built environment utilizes nearly 50% of total energy being used in developing / under-developed countries, while even in developed regions of the world this ratio is as high as 30%. Nearly half of the total primary energy, in Pakistan, is consumed by commercial and residential buildings, while they produce about 1/3 of total Carbon Emissions. Managing energy usage and Green House Gases (GHG) emissions has become a global challenge and its impact on the developing regions is causing immense problems for the population. It has, therefore, become extremely important to regulate and reduce the energy being consumed by the Built Environment. The authors in a related paper (Sheikh et al., 2018) also highlighted this.

It is feared that unless all countries across the globe take immediate positive action, the world carbon emissions shall double by the year 2030. For developing countries, this ratio is expected to be even higher due to their rapid development rates. Reducing carbon emissions is, therefore, becoming a priority in Pakistan as well. One way of achieving this goal is to minimize the energy consumed by the buildings and provide these minimized energy needs, using renewable energy sources. In Pakistan, with a population approaching 220 million people, out of which nearly 60% are youth. Due to this Pakistan's education system is extremely expansive. As per the data available from Pakistan Education Statistics 2016-17 (Shah et al., 2018) Pakistan's education system comprises more than 317,323 educational institutions that provide education to nearly 50.28 million students at any given time. It is, therefore, a foregone that these educational Institutions are a major energy consumer in Pakistan.

It has been observed that energy conservation in academic institutions can, not only provide major cost savings for the academic institutions but can also be instrumental in reducing carbon emissions in the country. So far, energy expenses in academic institutions are treated as unimportant in comparison with other priorities. However, historical trend analysis of academic institutions operating budgets shows that energy bills can constitute between 10 to 15 % of the total expenditure of the academic institutions and is generally the next highest expenditure after the salaries of the faculty and staff. Crosby & Metzger (Crosby & Metzger, 2013) concluded that in recent times, there has been an increasing focus on managing energy used in these institutions. It is considered that to achieve higher energy efficiency and conservation, it is important to bring awareness among students around the globe about conserving available

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energy resources, use of Renewables and mitigating the effects of Greenhouse Gases (GHG) on our global environment. In developing countries, the rate of increase of GHG emissions is much higher than that of the developed world as generally their rate of development is higher. In the case of Pakistan, the annual growth rate has increased from close to 3% to about 5.5% in the last 2-3 years, resulting in a large increase in GHG emissions.

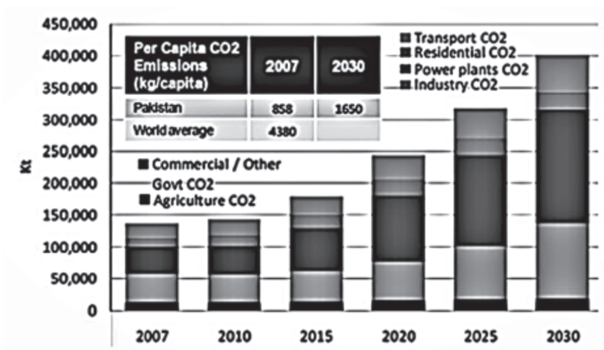


**Fig. 1: Pakistan sector-wise CO2 emission chart (Abas et al., 2017)**

The two sectors of Power Generation and Buildings has seen tremendous growth. As shown by Fig. 1 the installed capacity of electricity generation has gone up from 18,000 MW to 28,000 MW in the last 5 years and this is likely to go up to 36,000 MW in the next few years. This is likely to cause a further increase in GHG emissions in Pakistan unless immediate measures are not taken to control the emissions of pollutants. In comparison to global carbon emissions, Pakistan's carbon footprint currently is quite small, but it has started to increase rapidly (Abas, 2017) in the last few years due to a healthy growth rate of the economy.

As seen from the above data, emissions from the built environment are increasing alarmingly and several efforts have been made to achieve energy efficiency and reduce the carbon footprint of different categories of buildings (Pérez-Lombard et al., 2008; Kneifel, 2010; Ma et al., 2012; Gua et al., 2017; Chang & Chang, 2016; Berardi, 2017; Cong et al., 2015; Zhang, 2012; Olivier et al., 2019; Amaxilatis et al., 2017). Among the built environment, a major contributor is the academia related buildings (Bull et al., 2014; Airaksinen, 2011; Hong et al., 2012; Filippín, 2000; Chidiac et al., 2011; Allab, 2017) because of their sheer numbers. Various authors have observed that the thermal comfort is lacking in most academic buildings available to school-going children in developing countries; even where a large cost is being incurred on heating and cooling of academic buildings (Jindal, 2018; Yun et al., 2014; Liang et al., 2012; Mishra & Ramgopal 2013; Hwang et al., 2006; Teli et al., 2012; Kumar et al., 2016; Manu et al., 2016; Indraganti, 2010). Thus, improving thermal comfort by using efficient temperature control techniques and designing school buildings with inbuilt thermal comfort by using thermal energy storage (TES) (Lefebvre, & Tezel, 2017; Gracia, & Cabeza, 2015; Ndiaye et al., 2018; Heier et al., 2015; Berardi, & Soudian, 2018; McKenna et al., 2018; Saffari et al., 2017; Narain et al., 2016; and Li et al., 2018), providing natural ventilation (He et al., 2017; Aldawoud, 2017; Pieri et al., 2017; and Chen et al., 2017) and using optimum building orientation (Varoğlu, & Altın, 2017; Keplinger, 1978; and Hemsath, 2016) are priorities in developing countries.

## MATERIALS AND METHODS

For the purpose of this study a school located in Islamabad, Pakistan was selected. The selected school was built in 2004. The building of the school is a double story structure with 44 classrooms and a floor area of approximately 2240 $m^2$. The school has an enrolment of 1020 students on average. A detailed analysis of the School building energy consumption patterns is performed to identify energy-saving opportunities and the possibility of cost savings and reduction in carbon emission by improving the energy consumption of school buildings in Pakistan.

The main objective of the study was to identify areas in which schools can increase the efficiency of energy usage and bring about better energy conservation as well as achieve a substantial reduction in the school's energy bills. The study of the selected School was carried out through the following steps. The details of the energy consumed in the school building were established using three different methods.

Monthly energy bills for gas and electricity were analyzed to find basic loads and peak loads to pinpoint for what purpose the energy was used.

The electricity consumption for one week during the month of November was measured to ensure the accuracy of the bills. This one-week data was used to extrapolate consumption for the whole month of November for comparison as only the monthly energy consumption data were available in the records.

Energy usage simulation was carried out using the TRNSYS© software (TRNSYS 17, 2014) to establish the amount of energy being utilized by the buildings for heating, cooling, lighting, and ventilation. The typical meteorological year (TMY) weather data for the urban area of Islamabad, Pakistan is used to carry out the simulation.

### Gas bills

Monthly gas bills for the selected School were available in units of Hector cubic meter. ($Hm^3$). This data was converted into energy units (GJ) by using Eq. 1.

$$1\text{Hm}^3 \times \frac{100\text{m}^3}{1\text{Hm}^3} \times \frac{40\text{MJ}}{1\text{m}^3} \times \frac{1\text{GJ}}{10^3\text{MJ}} = 4GJ \quad \text{Eq. (1)}$$

### Electricity bills

Similarly, monthly bills for electricity were available in units of KWh. These were converted into primary energy (GJ) by multiplying monthly kWh by using Eq. 2.

$$1\text{kWh} \times \frac{3.6\text{MJ}}{1\text{KWh}} \times \frac{1\text{GJ}}{10^3\text{MJ}} \times 3 = 0.0108GJ \quad \text{Eq. (2)}$$

Using 33% efficiency for conversion of electricity into primary energy, the monthly gas, and electricity energy data was added and plotted as shown in Fig. 2.

After plotting the monthly values, a baseline load for the minimum or near minimum monthly consumption was calculated by conducting an Energy Audit. This load consisted of lighting, ventilation, pumps, and cooking, etc. Then this baseload was subtracted from the total monthly consumption to calculate the energy for heating and cooling as shown in Fig. 3. The base consumption value was then multiplied with 12 to obtain total annual consumption.

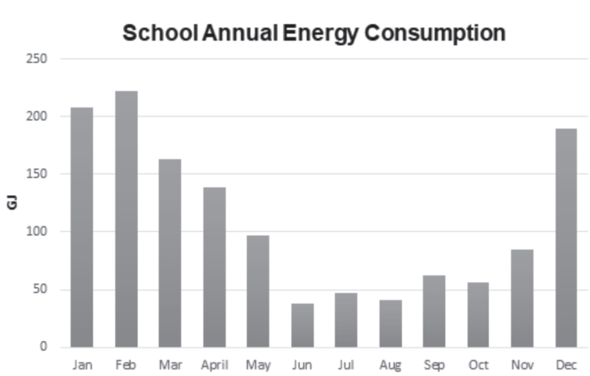


**Fig. 2: Annual energy consumption chart**

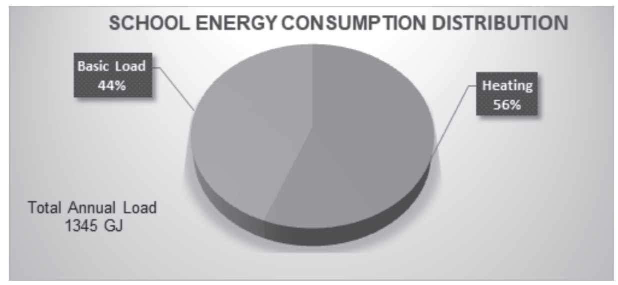


**Fig. 3: School energy consumption distribution**

## RESULTS

### Energy Measurement Results

A power telemetry device was designed and fabricated to record the electrical consumption of the building in kWh units. The device also had the capability to measure instantaneous power, frequency, power factor, current, and voltage. The device is shown in Fig. 4.

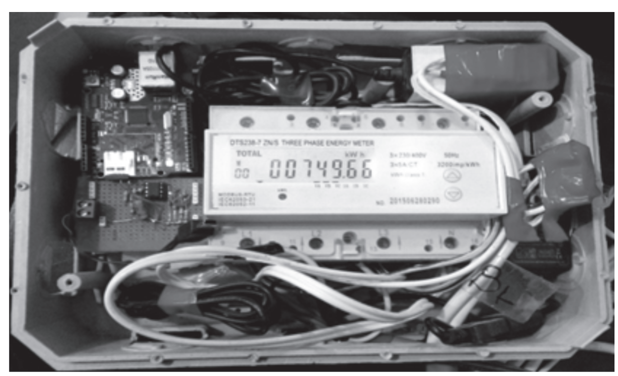

**Fig. 4: Power Telemetry Device**

The system comprised of the following components:

1. Three Phase Digital Power Meters

2. Arduino Mega 2560 (Controller)

3. RS 485 Communication Module

4. Current Transformer (CT) Sensors 200/5A

5. Wireless Internet Module

The system was integrated in such a way that it sent the measured values on to a web server after every hour and these values are plotted to see the electricity consumption of the building. This power telemetry device was installed on-site to measure electricity consumption in the School. The device also displayed this data online numerically and graphically for analysis. Graphical data received from the device on 18th November is given in Fig. 5.

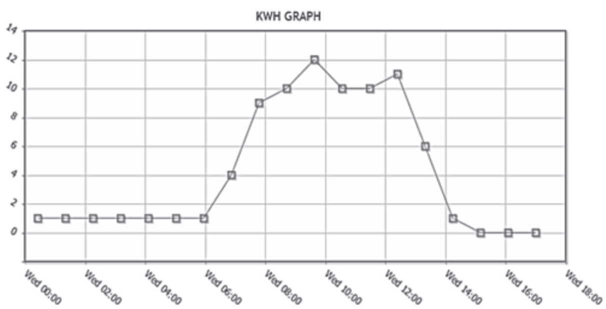


**Fig. 5: Hourly measured electricity consumption data**

The daily-accumulated electricity consumption measured by the device for one entire week of November is shown in Fig. 6 below.

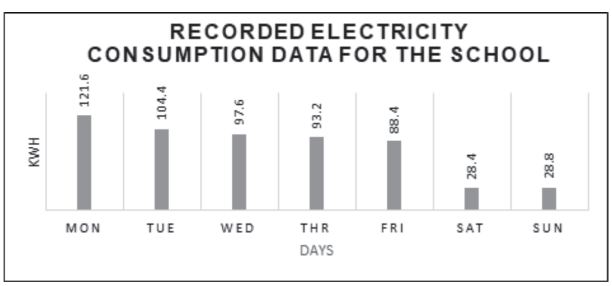


**Fig. 6: Electricity consumption data for the school for one entire week.**

When extrapolated for the full month of November, the total comes to 26.03 GJ which is in close agreement with the value calculated from the electricity bills. This validated the electricity consumption data calculated earlier from the utility bills.

## Simulation Results

TRNSYS© is a complete and extensible simulation environment for the transient simulation of systems, including multi-zone buildings. It can be used to validate various energy concepts, from simple domestic hot water systems to the design and simulation of buildings and their equipment, including control strategies, occupant behavior, alternative energy systems (wind, solar, photovoltaic, hydrogen systems), etc.

As the weather data for the urban Islamabad area was not available in the TRNSYS© libraries, the weather data file was generated in the required TMY2 (Typical Meteorological Year) format, using data acquired from Pakistan Meteorological Department. The monthly average energy requirement for the school building was simulated using TRNSYS© software. The components of the flow diagram used for simulating the energy usage is given in Fig. 7 below. The design of the school building envelope, building orientation and internal heat loads were input to the model.

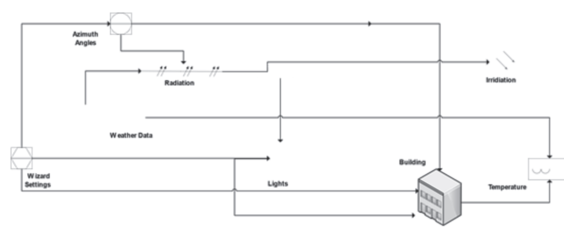


**Fig. 7: Simulation Flow Diagram**

## Building Mathematical Model

The building mathematical model described above was input into TRNSYS© for performing the thermal analysis. TRNSYS© carries out the analysis using energy flow across the thermal zones' boundaries. The TRNSYS© multi-zone building (TYPE 56) (TRNSYS 17, 2005) was used to model the school building.

## Analysis of Data

For comparison, the calculated data obtained from the TRNSYS© simulation model for each month was plotted against the energy data calculated from the energy bills (Fig. 8).

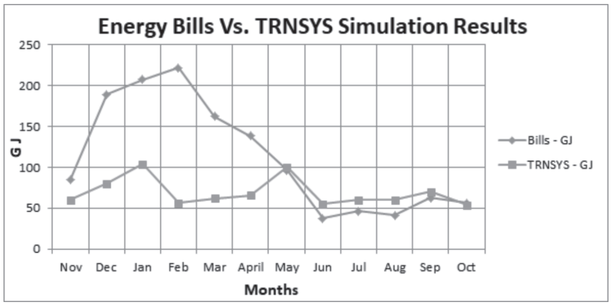


**Fig. 8: Energy bills data Vs. TRNSYS© simulation results**

Energy consumption simulations were performed using assumptions that the building interior temperatures are maintained at a minimum of 20°C in winter and no indoor temperature regulation is carried out during summer months of June, July and August (as these are the summer holiday months). During the rest of the year where temperatures are mostly within bearable limits and cooling is provided using fans and natural ventilation only.

**Winter Months**

The simulation results, when compared with actual energy consumption data (Fig. 7 above), show that actual energy consumption during winter months is much higher than predicted by the simulation results. The reason concluded for this discrepancy after the investigation was that the building indoor temperature was not being regulated in actual practice, thus allowing heating to raise the indoor temperature too much higher than the optimum 20°C. Additionally, an inspection of the building revealed that due to poor insulation and high outside air infiltration rate through the doors and windows, which were often left open, caused a large aggregate of energy losses. It was also noted that the gas heaters were old (older than 5 years) and used energy inefficiently. The old gas heaters not only used more gas but also posed a threat to the safety of the students due to the possibility of methane gas leakages and Carbon monoxide emission in the classrooms.

**Summer Months**

On the other hand, during the summer months, actual energy consumption shown by bills is somewhat lower than those of the TRNSYS© simulation results. The reasons for this were clear as the school remains closed for the three summer months and even most of the base loads are not in use during this time. The other months being milder, most fans can provide the required thermal comfort and the School does not use any air conditioning.

The comparison of the actual and simulation results for the energy required for school building to keep a comfortable temperature inside the building during working hours showed that several improvements including utilization of better gas heaters with temperature regulation and better sealing and insulation would result in substantial energy savings as well as provide a safer environment for the children.

**Building Layout Simulation Results**

The selected school building energy consumption was calculated both for the current building layout and for a more efficient H-configuration with the same number of classrooms and floor area, as depicted in Fig. 9 below. The improvement in energy consumption by the

H-configuration building shows that if during the design phase of the building, care had been taken in designing the building in line with good energy conservation practices, including layout design and building geographical orientation a large amount of energy could have been saved. This analysis was carried out to highlight the importance of good design practices for various stakeholders. The improvement in the performance of the building with the changed layout is shown in Fig. 9 below.

The simulation results show changing the existing building design to the H-configuration structure saves a large amount of energy annually.

Total Energy consumption of Existing Building = 306,111 kWh/year =3306 GJ/year …… (1)

Total Energy consumption of H-configuration Building= 214,352 kWh/year = 2315 GJ/year …… (2)

The energy consumption amounts calculated above; we can find the percentage of energy that could have to be saved annually if the building had been designed to be more energy-efficient from the beginning.

Annual energy savings possible = (3306-2315)/3306

× 100 = 29.9 %

**Cost-Benefit Analysis**

The following Energy Efficiency Measures (EEM's) were recommended to the School management based on the data analyzed.

- Windows double-glazing
- LED Lighting
- Gas Heater Replacement
- Behavior-Based Measures

The cost of energy saved has been calculated using the present commercial rate of primary gas of $6/GJ. The cost-benefit analyses of four identified energy efficiency measures are described below.

**Double glazed windows**

Glazing is the action of installing windows in a building. Single glazed windows are installed in the existing school building, by retrofitting of solid wall dwellings and have shown significant advantages of using external wall insulations including the use of double or triple glazed windows (Memon, & Eames, 2017). As only double glazed windows are available in the local market, their impact on Academic institution's energy usage was calculated through TRNSYS© simulations. These simulation results established that the School building energy consumption can be reduced by 245GJ/Year.

TRNSYS© simulation results gave the following energy statistics:

Current energy usage for winter season = 1704 GJ/year.

The energy requirement for the winter season with double glazed windows =1459 GJ/year.

Annual energy saving due to double glazed windows = 1704 GJ - 1459 GJ = 245 GJ/year.

Cost Saving / Year = 245GJ × $6 / 1GJ = $1,470 / year.

The current cost of installing double glazed windows @ \$ 36/$m^2$

Cost of installation of double glazing windows = \$ 36/$m^2$ × 528 $m^2$ = \$ 19,008

Payback =19,008/1470 = 12.93≈13 years

**LED Lighting**

Various studies have shown that LED lights have great potential to replace fluorescent lamps, mainly driven by the cost savings (Gan et al., 2013; and DOE, 2016). Most of the School lighting was currently based on CFL tubes and hence substantial opportunity existed for energy and cost savings if high efficiency LED lights.

Electricity Saving/Year=2.5W/m2 × (1120m2)/floor×2floors×8hr/day×20days/month × 12 months/year ×1kWh/1000wh = 10,752 kWh

Total Energy consumption=10,752 kWh ×3.6MJ/kWh × 1GJ/1000MJ = 39GJ Primary Energy saved=39GJ ×3 = 117GJ

Energy cost with LEDs =10,752 kWh × \$ 0.10/kWh=\$ 1,075

Energy cost with TL =25,920 kWh × \$ 0.10/kWh=\$ 2,592

Energy cost saving with LEDs =\$ 2,592 -\$ 1,075=\$ 1,517

Cost of LED's = (2.5×2240) W ×\$ 1/W = \$5,600

Payback=\$ 5600/(1517 ) = 3.69 years.

**Gas Heaters**

The simulation result shows that gas heating systems presently used in the selected School are inefficient. The amount of excess energy in the winter months comes out to be 362GJ. The saving cost, implementation cost and payback period are given below:

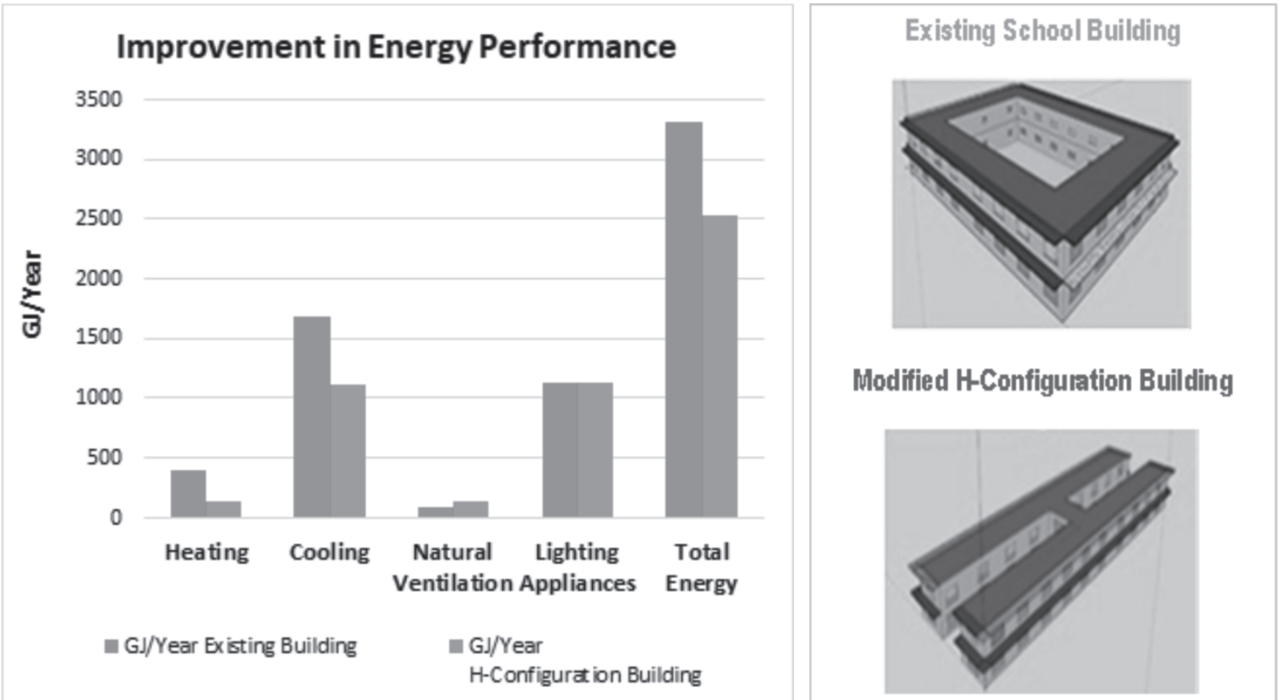


**Fig. 9: Improvements in Energy Performance of Buildings**

Energy-saving by replacing Heaters= 865GJ – 503GJ = 362 GJ

Taking Heater Efficiency = 80%

Total energy saving = 80/100×362GJ=289.6GJ

No. of heaters = 2 Heater/Room × 40 room = 80 Heaters

Cost of heaters = $95/Heater × 80 Heater = $7,600

Total Saving / Year = $6 / GJ × 289.6 GJ = $1,738/year

Payback period = $7,600 / $1,738 = 4.37 years

**Behavior-Based Measures**

It has been established that Academic institutions can save up to 20 to 37% of energy using behavior-based measures (U.S. EPA, 2011). However, to be conservative and from interviewing various stakeholders at the school it was estimated that initially through proper indoctrination approximately 10% of energy consumption per year can be saved using behavior-based measures, which amounts to an energy-saving of:

Total energy consumed by the building = 1345 GJ / Year

Energy-saving @ 10% = 134.5 GJ / Year

Cost savings = 134.5 GJ / Year × $6/GJ = $807 / Year

The table 1 below shows the implementation cost, benefits per year and payback period after implementation of these measures for the School building.

## DISCUSSION

The study highlighted that if the school building had been designed with consideration for energy savings, up to 30% energy conservation could have been achieved with a better building layout (optimally orientated H-configuration). Other measures like improvement in window glazing (18.21%), Lighting (8.7%), gas heating (21.53%) and behavior pattern (10%) also result in substantial savings as mentioned against each measure. The total achievable monetary savings represent approximately 58 % of the cost of energy currently used by the Selected School building. Additionally, these energy savings equate to an average energy consumption index of 1.12 GJ per student per year and an annual greenhouse

**Table 1: Results summary**

| EEM | EEM Implement Cost | Savings | | | | | Payback Period |
|---|---|---|---|---|---|---|---|
| | | Annual Energy Savings | | Energy Saving Cost | Energy Savings | Carbon Savings | |
| | $ | GJ/year | kWh/year | $ pa | % | T CO2 | Years |
| Windows Double Glazing | 19,008 | 245 | 22,685 | 1,470 | 18.21% | 11.50 | 12.93 |
| LED Lighting | 5,600 | 117 | 10,833 | 1,517 | 8.70% | 5.40 | 3.69 |
| Gas Heaters | 7,600 | 290 | 26,815 | 1,738 | 21.53% | 13.45 | 4.37 |
| Behavior Patterns | 0 | 135 | 12,454 | 807 | 10.00% | 6.25 | 0.00 |
| H-Configuration Building Layout* | N/A | 991 | 91,759 | N/A | 30.00% | 25.4 | 0.00 |
| Total | 32,208 | 1,777 | 164,546 | 5,532 | | 62.0 | 5.82 |

* Possibility existed only if the design was implemented prior to building the school.

gas emissions equivalent to 62 tonnes of $CO_2$ or 0.061 tonnes of $CO_2$ per student per year.

## CONCLUSIONS

In this paper, the study was able to establish the current energy consumption pattern for the selected School. This helped to identify energy efficiency measures (EEM's) to reduce the energy consumption of the School. Results achieved from various analytical and computational methods highlighted the fact that energy flow in the building can be improved substantially. Various hidden opportunities for energy saving were made evident. Though simple analysis of energy bills does not provide any insight into energy-saving opportunity, however, when actual energy consumption data is compared with TRNSYS© simulation results a large potential for saving energy used for heating the building in winter months can be seen.

Among the energy efficiency measures (EEM), the behavior patterns, though not costing anything, are the most difficult to implement. However, if implemented, behavior-based measures yield a number of important benefits including spreading the message of energy conservation to the larger community through the students. The lighting and gas heater replacement is the next to energy efficiency measure in the order of payback and is recommended to be implemented as early as possible. The replacement of window glazing needs major investment, has a longer payback period, and therefore, is recommended to be implemented last.

If these results are seen from the perspective of the statistics showing that the education system of Pakistan (Sheikh et al., 2018), comprises of 317,323 educational institutions and is educating nearly 50.28 million students at any given time (a number greater than population of more than 204 individual countries out of the 233 countries listed by UN in its population statistic (UNESA, 2017). The immensity of these figures highlights the massive opportunity that exists in this area alone, for mitigating global environmental impact. The current year (2018-19) education budget of Pakistan is PKR 97.4 billion or USD 0.7 billion. Out of this, about 90% is utilized in the running expenses of the educational institutes. The results show that per student saving of USD 5.42 can be achieved. This translates to USD 272.7 million in savings per annum. Thus, if proper energy conservation measures are taken the effect would be as if approximately 39% of the education budget is enhanced, giving a much-needed boost to the education system in Pakistan.

The total $CO_2$ emissions reduction theoretically possible by improving the building design of academic institutions thus falls in the region of 3.07M tonnes annually. Though this reduction is only 1.43% of Pakistan's huge 214M tonnes of annual $CO_2$ emissions. However, this is a start and if similar options are considered for the entire building sector in Pakistan, substantial savings in GHG emissions can be achieved. Therefore, this study is also very important as it highlights that Pakistan needs to take a policy decision with regard to stricter building codes if it is to achieve the UN Sustainable Development Goals by 2030.

**Funding**

This research was funded by 50% by the Higher Education Commission of Pakistan (HEC) through grant No: 20(027)/SIOP/R&D/20l6 dated May 25, 2016, and 50% through internal R&D funding of Air University, Islamabad, Pakistan.

**Acknowledgments**

The support of the Air University Mechatronics Engineering Department and Lab staff was crucial in the completion of work.

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