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# ENERGY IN SCHOOLS – AN ENERGY AUDIT CASE STUDY

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## ABSTRACT
This paper presents results of one of the first audits out of the six that are pipelined for the national project "Energy Efficiency and Conservation for the Building Sector of Botswana". The project undertakes energy audits using state-of-art technology and simulation software Designbuilder. Results of the audits and simulation serve as indicators for energy policies, standards and maintenance manuals that are to come out of the project. Early results show that buildings in Botswana are generally not energy conscious.

## KEY WORDS
Energy, Energy Audit, Energy in Schools.

## 1. INTRODUCTION

Over recent years Botswana has seen large growth in energy consumption and increased dependence on imports of especially petroleum products and electricity. More than 70% of the latter is now imported. Forecasts all show a continuation or even worsening of this trend, driven by growth in GDP, growth in population and the rural electrification efforts [1,2,3]. These developments give rise to concerns over the security of supply since electricity generation capacity in the entire Southern African region is, and will continue to be for many years to come, stretched to the limit. In addition, there is the complementary concern that this will also very quickly drive electricity prices to new heights [1,2,4]. These local constraints exacerbate the international trends of high and increasing oil prices and concerns over climate change driven by combustion of fossil fuels [5]. The strong reliance on coal for electricity generation is an additional concern for Botswana and the Southern African region as a whole.

In terms of electricity consumption the fastest growing sectors over the last five years have been the government and residential sectors, where most of the energy consumption is in buildings, which account for about 30% of total electricity consumption [3]. Thus not only is energy usage in buildings significant in its own right, but also exhibiting the strongest growth rates [3].

It is widely recognised that buildings in Botswana exhibit large potential for energy savings and energy efficiency improvement in terms of both design and operation (energy management). The small degree of attention given to energy efficiency in the design of buildings is critical, considering that buildings have a long life span and that such deficiencies therefore act over a very long time. Documentation and quantification of this potential, however, is sparse and the assessments are mostly based on general observations and experience from similar environments.

In recognition of this background the Government of Botswana has initiated a three-year project on improving energy efficiency in the building sector in cooperation with and co-funded by Danish International Development Assistance [6]. The project is entitled 'Developing Energy Efficiency and Energy Conservation in the Building Sector, Botswana' and is implemented by the Department of Energy, Ministry of Minerals, Energy and Water Resources (MMEWR) with the assistance of an international team of consultants led by a Danish Consulting Firm; Danish Management Group [7].

The core activities of the project address energy efficient design of new buildings, improvement of energy performance of existing buildings, raising the profile and awareness of building energy efficiency amongst various professional groups and strengthening of educational efforts. Among the specific activities are a number of detailed building energy audits; development of guidelines for good practices in design of energy efficient buildings and strengthening of energy management. An important activity led by the Department of Energy will also be to hold a building design competition in cooperation with the Department of Building and Engineering Services (DBES) to demonstrate such principles in a specific building. This differs from e.g. the new Botswana Technology Centre (BOTEC) building, the purpose of which was largely to demonstrate and test innovative design elements in the Botswana context, whereas the purpose of the mentioned design competition will be more to lead by example through use of integrated building energy design using well known technologies and methods.

This paper presents the findings from one detailed energy audit carried out through the aforementioned project. It not only provides firm documentation of widely held beliefs on energy savings opportunities, but also through this gives an indication of the nationwide energy conservation potential.

## 2. AUDIT OBJECTIVES

The following are parameters that the audit investigated about Ramotswa Junior Secondary School:

(i) Indoor environmental quality (IEQ): Buildings and their service equipment have to deliver what is expected of them in terms of air temperatures, humidity, carbon dioxide concentration, air velocity, lighting levels, etc. Often failure to meet such requirements (especially energy related ones like temperature) is reflected as low consumption of energy, which is a false signal. This audit therefore investigated the performance of the building vis-à-vis its energy consumption.

(ii) Energy Utilisation Index (EUI): These are energy consumption figures that are comparable to established benchmarks like electricity consumption in $kWh/m^2\cdot yr$ or kWh/student·yr.

(iii) Variation Patterns in Consumption: There are some weather related variations in energy consumption and when these are clearly understood, weather related measures, like adding insulation, can be quantified in economic terms. Correlation with heating degree-days was investigated as well as with occupancy where applicable. Generally, if a building uses high electricity while there is no occupancy, further investigations are carried out focused on equipment that could be left on overnight like computers, lights and 24 hours equipment like geysers.

(iv) Energy Consumption Break-down: Breaking down energy consumption according to type of equipment in the building allows decision-makers to identify the most energy consuming equipment and the general rule is that they offer the highest saving potential when energy efficiency and conservation measures are implemented on them. Where there are many buildings like in a school setup, the audit attempt to breakdown consumption according to building units.

(v) Materials of Construction: Performance of buildings is affected by thermal characteristics like the coefficient of thermal heat transfer (U-value) for walls, windows, roofs and floors. These were covered by the audit.

(vi) Economic Analysis: Simple payback period and life cycle costing in discounted cash flows were performed on different and reasonably feasible intervention measures.

## 3. AUDIT METHODOLOGY

The audit methodology was largely influenced by the ETF Training Manual [8]. First a preliminary audit was carried out with the intention to find early signs of energy wastage and failure in indoor environmental quality (IEQ). Electricity bills were acquired for at least three recent years and regression analysis performed to assess seasonal variations, relationship with heating degree days, and consumption indices like $kWh/m^2\cdot yr$. If the building gives early signs of high consumptions or saving opportunities, the audit team considers it for a detailed audit. Once selected for such, a detailed audit plan was drawn, defining the audit scope. The detailed audit started with a site visit by both the audit and operation and maintenance (O&M) consultants at which the number of distribution boards was identified and the physical and equipment security matters studied and considered in the audit strategy. The occupants were also sensitised about impending work and participation sort. Auditing equipment was then connected at strategic points and rotated around the building system at stipulated intervals. Such equipment included non invasive current/voltage loggers, energy analysers, plug-in kWh meters, relative humidity/carbon dioxide loggers, temperature loggers (air and surface), as well as voltage anomaly loggers. Spot measurements were carried out at some intervals on lux levels, wind speed and radiant temperatures (the latter with infra-red meter). With the logged data, consumption was broken down according to equipment like lighting, heating ventilation and air conditioning (HVAC), catering, water heating and computers, as found fit for the building. For schools with many building units, the total consumption is also broken down according to the building units.

Energy intervention measures that could not be measured post construction e.g. double skin wall and orientation were quantified using simulation by energy simulation software called Designbuilder. For this, weather data was obtained from the local meteorological station and local research centres like the University of Botswana.

Finally, with results from both the logged data analysis and simulation, possible intervention measures were assessed for their economics in terms of simple payback, internal rate of return and life cycle costing. A report was then written detailing the whole audit.

## 4. RAMOTSWA JUNIOR SECONDARY SCHOOL

Ramotswa Junior Secondary School is located in Ramotswa, a village about 25 km south of the capital city of Botswana, Gaborone. The school has 436 students, 23 of whom are boarding. The latter are the special education (deaf) students. The boarding students have two boarding masters (one for the boys and one for the girls) who are also resident within the school. Electricity used to support boarding students and masters forms part of the school's consumption since they are connected downstream of the main supply meter. Their consumption includes electric water heating for showers in both hostels, ironing in the hostels and masters quarters, electrically backed up solar water heaters in the masters' quarters, incidentally used electric stoves in the masters' quarters, domestic lighting, four 400W exterior lighting for the two hostels and some general domestic use. Cooking for the students is done by gas (LPG) unlike in other schools ([9],[10],[11]) and therefore lowers the otherwise possible electricity burden. Boarding students are resident only during term times while their masters are resident throughout the year.

## 5. RESULTS AND DISCUSSIONS

### 5.1 Indoor Environmental Quality (IEQ)

Figure 1 shows the daily average hourly room temperatures for different locations in the school over a data logging period of about 20 days over the month of February 2006. The reference temperature is the outdoor temperature. The grey background is the occupied period. The temperature in most rooms hovers at 27°C and above during the occupied time. This is more on the discomfort side for most occupants since the summer comfort zone is 21 – 27°C, according to ASHRAE Standard 55 [12]. When outdoor temperatures are below room temperatures, there is an opportunity for cooling by natural ventilation. This does occur quite commonly for some rooms like the kitchen. During the night the outside temperature is almost always lower than indoor temperatures, giving a better opportunity for thermal mass and cooling by natural ventilation. This phenomenon is not well exploited in this school and others ([9],[10],[11],[13]). In the kitchen there are ceiling mounted fans at ceiling height which is about 3m above floor. Hot fumes from the cooking pots ascend to the ceiling level and the fans blow the fumes back onto the occupants, making a bad situation worse. As a result the fans are no longer used. Interviewed catering staff has raised fears for their health given the hot and stuffy atmosphere they work under for the whole of their employment with the school.

The server room is another room that raised issues of concern: daily average hourly temperatures in the server room ranged from 15.5 °C to 16.5 °C (Figure 1). The reason given was that the server has to be kept at some low temperatures hence an air conditioning split unit rating about 1400 W is kept running throughout the term time with a set-point of 16°C. The set-point of 16°C is too low and can be adjusted to some 22 °C without any harm.

Spot measurements of carbon dioxide concentration were taken in various rooms. Measurements in classrooms, staffroom and kitchen varied between 380ppm and about 650ppm, signalling plenty of ventilation in the rooms. The computer room, with no operable windows, have registered concentrations between 1700ppm and 2830ppm when occupied. By comparison with other rooms this is too high, but it still conforms to 3500 ppm set by Canadian standards (as quoted in ASHRAE Fundamentals [14]).

With lights off in a cloudy day, illumination levels measured ranged from 130 to 400 lux, averaging 231lux. This showed good opportunities for natural lighting. With lights on, levels ranged from 230 to 400 lux, averaging 298 lux. This reasonably meets requirements of the CIBSE Guide [15], which set classrooms at 300 lux.

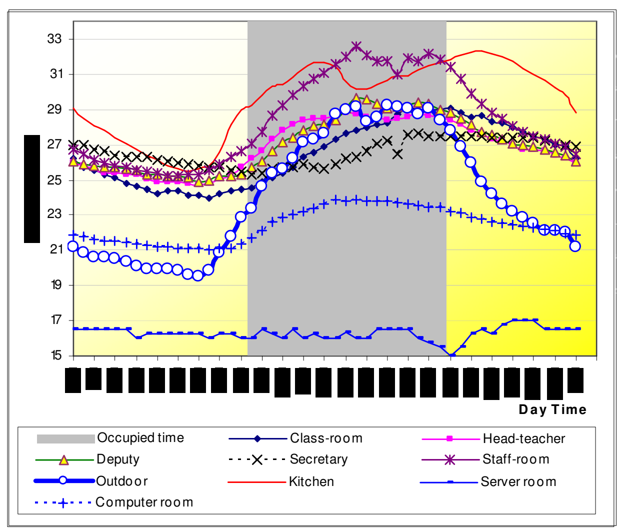


**Figure 1:** Daily average hourly ambient air temperature in various rooms in the school (week days only).

Figure 2 shows the frequency of occurrence of temperatures in various rooms in the school. Around 90% of the area under each graph is expected to fall within the comfort zone (grey area) but unfortunately an average of 21.9% of the time the temperatures in the studied rooms (with exception to the server room and outdoor) conformed to the comfort zone (grey area). The classroom studied conformed 41.9% of the time, albeit it exceptionality of having curtains and heavy walls with considerable thermal mass. The rest of classrooms were of poorer architectural features and are expected to

which shows consumption on the mildest months of April as 8,474 kWh/month.

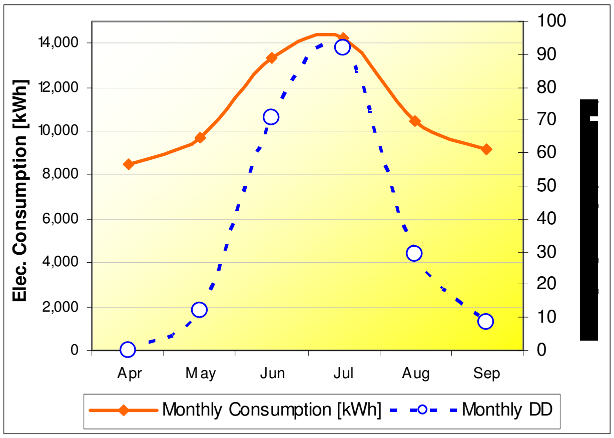


**Figure 4:** Electricity Consumption against Gaborone heating degree-days

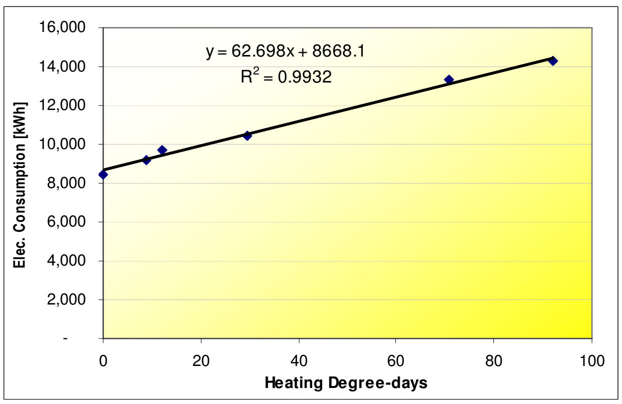


**Figure 5:** Base-load investigation using a plot of consumption against heating degree day.

Two approaches were adopted in breaking down the energy consumption in the school. The first was to break down the energy according to equipment type (Table 1). The second was to break it according to building units in the school (Table 2). This enables intervention measures to be focused on the highest consumers.

## 5.2.4 Breakdown of Energy Consumption by Equipment Type

Table 1 presents the findings of electricity consumption by equipment type. Lighting is found to consume the highest percentage (30%). Lighting is divided into two groups of interior and exterior lighting. Second to lighting is office equipment at 29% and domestic water heating at an estimated 27%, then HVAC at 21%. Kitchen and laboratory equipment consume least in the school.

Table 1: Breakdown of electricity consumption according to equipment type

| Equip. Type | Installed Power | Annual Energy Use (Elec) | % of total Energy |
|---|---|---|---|
| | [kW] | [kWh/yr] | |
| *Interior lighting* | *18* | *32,724* | 24% |
| *Exterior lighiting* | *4* | *7,904* | 6% |
| **Overall lighting (interior + exterior)** | **22** | **40,628** | 30% |
| Office Equipment | 13 | 40,120 | 29% |
| Domestic Water Heating | 16 | 36,763 | 27% |
| HVAC | 29 | 28,175 | 21% |
| Kitchen Equipment | 37 | 13,185 | 10% |
| Laboratory equipment (D&T) | 6 | 956 | 1% |
| Other (unexplained) | - | - | |
| **Modelled Consumption [kWh/yr]:** | | **159,827** | 116% |
| Compare w ith bill (kWh/yr): | | **137,400** | |

## 5.2.5 Breakdown of Energy Consumption by Building Unit

As shown in the summary table (Table 2), the hostels are responsible for 33% of electricity consumption in the school, followed by the computer suite at 28% and night time illumination at 16%. Energy utilisation index (EUI) varies from as low as 8 kWh/m$^2$·yr for the library and art laboratory, to as high as 302 kWh/m$^2$·yr for the computer room.

## 5.2.6 A Probe into Domestic Water Heating

The degree-day regression analysis had shown a highly weather related load. That, together with a high weekend load culminated in a further investigation dedicated to domestic water heating in the hostels. Data logging was done in the girls' hostels of 13 students and it was assumed that the boys' hostels (also 13 boys) would be roughly the same. The recordings made in the girls' hostels were thus multiplied by a factor of 2. Figure 6 shows the consumption pattern for the geysers on an average weekday for the month of March. In the figure, it can be observed that major usage of hot water occurs between 0430hrs and 0830hrs in the morning (local time) and again between 1530hrs and 2200hrs in the evening. These are the times at which students take their showers. It was noted that during the night-time off-peak hours (when the consumption is expected to be zero), an average consumption of 1,144 W is maintained due to losses to atmosphere. During the day, $\Delta T$ is smaller and the losses are reduced to an average of 852 W. These losses were estimated to contribute to 6% (616 kWh/month) of the total monthly bill for an average month of March. This is ascribed to heat losses from the body of the storage tank and bare piping exposed to low night time temperatures, as well as the high thermostatic setting of 65°C, hence high temperature differential (ΔT), which is the driving force. It ought to be borne in mind that these measurements were taken in a mild month of March and in winter these losses will increase drastically (as evidenced by Figure 3).

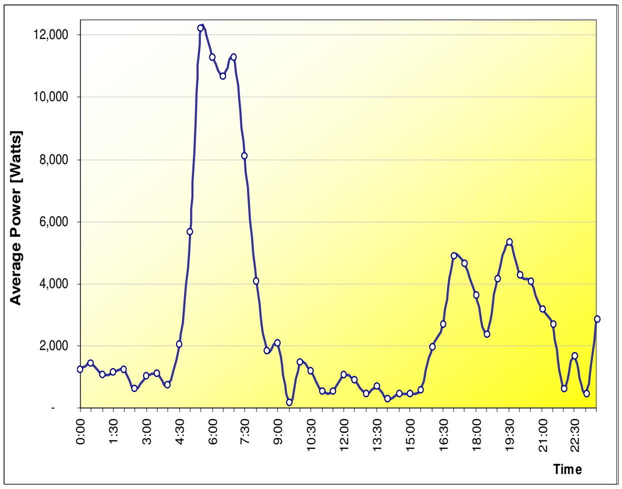


**Figure 6:** Consumption pattern of electrical geysers in the hostels

When the two boarding masters' quarters are included in the estimation, a conservative figure of 3,064 kWh/month is estimated to go to geysers only. Again the figure will be much higher during the winter months when ΔT is high and other domestic activities like dish-washing and laundry resort to hot water. With reference to a situation where there was no boarding, it can be said that boarding related water heating has increased consumption by 41% to be what it is in the month under investigation (a lot more in winter). It must also be noted that other fuels like LPG which is used for cooking everyday meals in the kitchen and boarding masters' quarters have been excluded.

## 5.2.7 A Probe into the Computer Room

Three probes were done in relation to the building: the first was the investigation of the total consumption of the building irrespective of the equipment in it, the second was the consumption of the computers (excluding HVAC and lights) and the third (last) was the consumption of the server room air conditioning system. Findings of these probes were used as measurement and verification (M&V) figures for the school's overall model.

The core findings of the probe were that an average of 5,460W was consumed during night time hours and weekends when the computer room was not in use. This is mainly caused by the computers that are left on and the server room air conditioner that is on 24 hours a day throughout the term period. The computer room constituted 33% of the average monthly bill (March), nearly 25% of which is avoidable by stopping all unnecessary off-peak consumption. This needs a no cost measure of developing a culture of switching off computers when not in use, coupled with setting the power saving mode of computers to automatically switch off when not in use for a stipulated period of time. The set-point of the server room air conditioner is 16°C, maintaining an average power consumption of 2,287W. This is not justified for a room that virtually needs only the uninterrupted power supply (UPS) on during class time.

The two probes indeed found that boarding related water heating, coupled with poor use of the computer room, contributed amongst the highest to the school's electricity consumption. The average hourly consumption of the two were laid one on top of the other in Figure 7, and compared with an average hourly school total consumption (line graph).

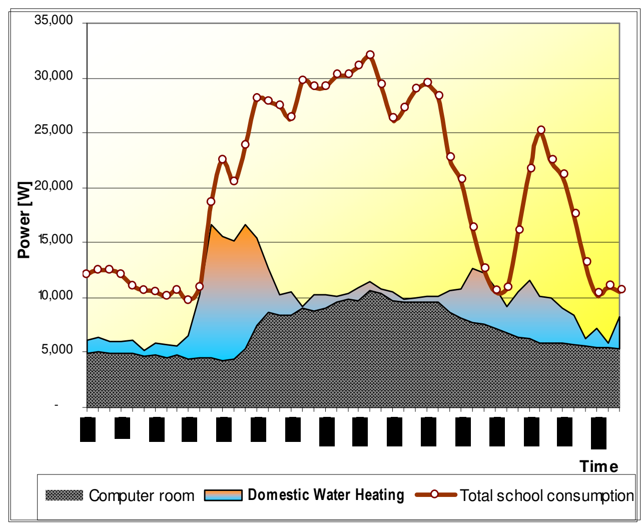


**Figure 7:** An overlay (one on top of the other) of consumption patterns show the significance of computers and domestic water heating

## 5.2.8 Energy Simulation

Designbuilder simulation software was used to model the computer room "As-Is" (Figure 8), verify the model against measured data and then simulate seven alternative scenarios of painting the roof white, ventilating the ceiling void, increasing ceiling insulation from 30mm to 100mm, adding insulation under the roof sheets, insulation between walls, double glazing and adjusting set-point temperatures such that less cooling and heating are needed from the air conditioning system.

The economics of all alternative designs simulated gave long payback periods ranging from 10 years up in strict money terms. However, painting the roof white reduced average summer indoor temperatures by 2°C, which makes a significant difference in non quantifiable returns like comfort and productivity.

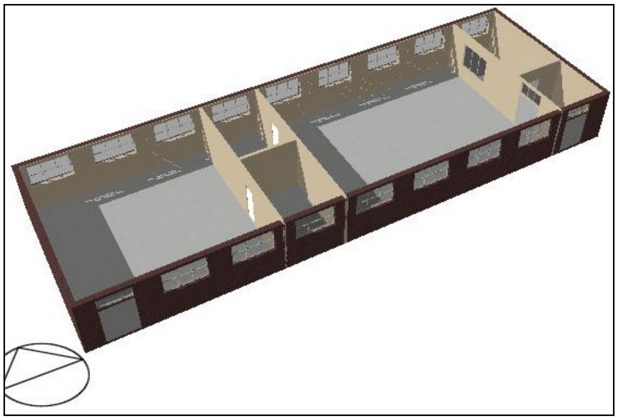

**Figure 8:** Simulation by Designbuilder software

### 5.2.9 Energy Utilisation Indices

The energy utilisation indices (EUI) relate the energy consumed to floor area and where appropriate to number of students. The school has 436 students, consumes about 116,800 kWh/yr (ranging from 90,806 kWh/yr for 2002 to 137,400 kWh/yr for 2004) and thus has an average energy utilisation index (EUI) of 268 kWh/student·yr. This compares unfavourably with other schools like Bokamoso Junior Secondary (EUI of 110 kWh/student·yr) [13] and Ledumang *'Senior'* Secondary (EUI of 256 kWh/student·yr) [9]. The reason for such a high EUI is because of boarding and an imprudent use of the computer room.

## 6. CONCLUSIONS

An energy audit has been successfully carried out at Ramotswa Junior Secondary School. Indoor environmental quality (IEQ) in the school does not meet expectations – temperatures are higher than the upper comfort limit of 27°C for over 50% of the time in most rooms, and some rooms like the computer room, with no ventilation, have comparatively high $CO_2$ concentrations averaging 2423ppm (maximum recorded 2803 ppm). Numerical figures of energy utilisation indices are captured in Table 2. The school has a clear weather related consumption pattern which is high during winter due to domestic water heating in the hostels and boarding masters' quarters. Hot water for boarding constituted 27% of the school's total consumption in the mild month of March and is expected to be more in winter and annually. Read backwards, boarding brings a 41% increase in annual bills to a '*non-boarding'* school situation by domestic hot water only. Lighting constitutes the highest consumer at 30%, followed by office equipment (29%) and domestic water heating (27%). Office equipment is high partly because computers are not switched off when not in use. Simulation has revealed that altering the building to reduce heating and cooling costs has payback periods in the order of 10.4 years for painting the roof white and 14.5 years for adding insulation to the inner surface of the roofing sheet. Of the two, painting the roof white seems more attractive in that it has lower initial cost, it does not require high specialist knowledge and most of all, during the refurbishment, it poses less threat of physically damaging structural elements like ceiling and roofing sheet. In strict money terms these may look unattractive, but considering the fact that they improve the indoor environmental quality (IEQ), they deserve to be looked at as investment in productivity of more than half a million students across Botswana's primary and secondary schools [19].

## 7. RECOMMENDATIONS

(i) No cost (or low cost) measures like energy awareness campaigns should be provided to schools to save a lot of energy and money.
(ii) Adjust cooling set-point temperatures for the server room from 16°C to 22°C or higher.
(iii) Lower set-point of electrical water heaters in the hostels from 65°C to 50°C. Also, insulate hot water distribution pipes for these geysers. Time switches may also be installed to switch geysers off at times when they are not required.
(iv) Ensure regular maintenance is done in the school. Change of filters in air conditioning systems and repair of ceiling fans and their control switches should be done.
(v) Replace the four 400W (totalling 1600W) floodlights in the hostels with several well spaced 70W high pressure sodium lamps or better.
(vi) Install a Fume Extract System in the kitchen to remove excessive fumes and lower the temperature.
(vii) Add insulation on the inside surface of the roofing sheet to reduce indoor temperatures and improve productivity.
(viii) Painting the roof of the Computer Room white is another possible option to reduce indoor temperature by an average of 2°C.

## ACKNOWLEDGEMENTS

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**Table 3:** Summary of audit results (electricity only)

| Building Unit | Built-in Area [$m^2$] | lighting Power [W] | Glazing to Wall Ratio (%) | Av. Illuminance (Lights OFF) [lux] | Expected Illuminance (CIBSE) [lux] | $CO_2$ level [ppm] | Overall Installed Power [kW] | Intalled Power Density (elec only) [$W/m^2$] | Energy Utilisation Index (EUI) [$kWh/m^2 \cdot yr$] | Annual Energy Use (Elec) [kWh/yr] | Annual Cost (Elec) [BWP/yr] | % of total Energy |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Boarding students & staff | 252 | 1,764 | 10.5% | 100 | 300 | - | 39.3 | 156 | 181 | 45,636 | 18,952 | 33% |
| Computer Room | 128 | 1,681 | 19.5% | - | 300 | 2,423 | 13 | 103 | 302 | 38,534 | 16,003 | 28% |
| Night-time usage | - | 5,941 | - | - | - | - | 4 | - | - | 21,519 | 8,937 | 16% |
| Admin. Block | 261 | 2,728 | 14.9% | - | 500 | - | 29 | 111 | 35 | 9,162 | 3,805 | 7% |
| Classrooms | 589 | 4,530 | 9.0% | - | 300 | - | 6 | 10 | 12 | 6,804 | 2,826 | 5% |
| Catering | 474 | 1,467 | 17.5% | 1,200 | 300 | 400 | 7 | 14 | 8 | 3,578 | 1,486 | 3% |
| Laboratory (Science) | 227 | 2,297 | 15.3% | 220 | 300 | 443 | 4 | 16 | 11 | 2,587 | 1,074 | 2% |
| Technical Drawing (TD) | 142 | 1,276 | 13.0% | - | 750 | 393 | 7 | 48 | 17 | 2,437 | 1,012 | 2% |
| School Tuck-shop | 8 | 128 | - | - | 100-200 | - | 1 | 66 | 280 | 2,242 | 931 | 2% |
| Laboratores (Home Economics) | 76 | 702 | 11.7% | 320 | 300 | 426 | 16 | 205 | 27 | 2,033 | 844 | 1% |
| Library | 131 | 766 | 9.8% | 70 | 300 | 570 | 4 | 28 | 8 | 1,018 | 423 | 1% |
| Laboratory (Art) | 110 | 766 | 19.1% | 400 | 750 | 279 | 1 | 8 | 8 | 899 | 373 | 1% |
| Unexplained | - | - | - | | - | | - | - | - | - | - | |
| **OVERALL SCHOOL** | 2,398 | 24,045 | 13% | | | 705 | 129 | | | **136,447** | | 99% |

Compare with average utility bill [kWh]: **137,400**


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