Energy Consumption due to Lights

HSS636 Term Paper

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MS18148

April 21, 2022

Contents

1 Introduction

Artificial lighting is a major contributor to electricity consumption globally. According to the estimates of the Global Lighting Challenge (GLC) in 2020, in the residential sector, lighting consumes substantial energy at the global level i.e., 15% [1]. The majority of residential and industrial lighting in the world is provided by incandescent light bulbs (ILB) and fluorescent lamps. Even worse, people in rural areas in developing countries have to depend on costly and inefficient fuel-based sources, like kerosene lamps which produce significant levels of Black Carbon (BC) emissions, as was reported by a 2012 study [2]. In a 2021 study [8], it was estimated that hypothetically, if we could make a switch to LEDs overnight, then it would save 800 million metric tons of CO_2.

However, there are a lot of social, economic, and environmental factors associated with making this switch. Although LED lights have a longer lifetime, the initial investment of buying them is relatively higher than its less efficient counterparts (however, the prices of LEDs are expected to significantly decrease in the coming years). Lim and colleagues (2012) [3] have also discussed that the production of LED lamps requires a greater quantity of metals compared to ILBs or CFLs. These factors may influence the speed of phase-out of older inefficient lighting technology, even though LEDs perform much better in every aspect in the long run.

The last few years have seen a significant reduction in the price of LEDs, and the UJALA scheme of the Government of India has been a big game changer [4]. Since its inception, the annual sales of LED lamps in India has grown by about 130 times [5]. The initiative has since inspired other nations to push for phasing out of inefficient light sources and promote the use of LEDs.

On a broader scale, there are plenty of other factors and stakeholders associated with making a switch to LED alternatives. However, we will not worry about the global scope and implications of this replacement drive. We will only focus our attention on the impacts of this project on the scale of IISER Mohali.

2 A case study of IISER Mohali

For the last few years, the electricity bills in IISER Mohali have constantly been rising. The rise in consumption has been a significant cause of concern since it can indirectly lead to a budget cut in several other functionalities of the institute. Therefore, every person associated with the institute is a stakeholder in this matter.

It is believed that the inefficient lighting sources being used on the campus are significant contributor to the high electricity bills. Most of the lighting equipment used in hostels still consists of traditional tube lights and CFLs. A majority of the labs in the Academic Block still have halogen light fixtures that draw out significant power in turn for a very nominal luminosity flux. Only recently has there been a change where LED alternatives are replacing faulty fixtures; however, their availability is limited due to the lack of investment on this front.

The goal of this term paper is to get an estimate for the fraction of total energy consumption that is due to lights, calculate the logistics of a hypothetical LED replacement drive, and predict whether such a drive would be beneficial on the economic as well as the environmental front. Such a calculation consists of three major steps -

1. **Count** the number of different types of lights present at various sites in the campus.
2. Collect information about the **time** for which the lights are generally switched on.
3. Collect information on the **power** rating of various light models.

Upon knowing the above three, we can do an order of magnitude estimate to calculate the total energy consumption due to the lights.

3 Methodology

In this energy audit survey, we were only able to do a detailed survey of Hostel 5 (and some locations of Hostel 7), and the 5th floor of AB-2. Since the structure of hostels and AB is symmetrical, we multiply the data collected in these locations by the appropriate multiple to get an estimate of the lights present in the Hostels and the ABs.

3.1 Different types of lights

In this subsection, we will give an overview of the type of lights present in the institute and give them some notation to make referring to them later on a little easier. The various light models are as follows -

- T^4 4×18W tubelight fixture
- H^2 2×36W halogen tube fixtures
- T 28W single tubelight
- D 11W single CFL dome shaped fixture
- L 18W single LED tube
- ℓ 9W small LED tube
- m 5W mini LED tube
- α^2 2×11W thin CFLs
- U 20W long CFL tube

- b 15W balcony CFL
- C_9 9W CFL bulbs (used in washrooms)
- C_{13} 13W CFL bulbs (reading light in hostel rooms)

(a) T^4 (b) H^2 (c) T

(d) D (e) L (f) ℓ

(g) m (h) α^2 (i) U

Figure 1: Different light fixtures throughout the campus.

(j) b (k) C_9 (l) C_{13}

Figure 1: Different light fixtures throughout the campus.

As mentioned before, using this list of different light fixtures, the number of each of these were counted and put down in a table. This information will be presented in the upcoming sections.

3.2 Algorithm for energy consumption calculation

Let's say we have a light source L_i which has N_i copies of it present throughout the campus. Let's assume that there are M different rooms in which this fixture is present. We can then say that n_{i1} of these fixtures are turned on for time t_{i1}, n_{i2} of them for time t_{i2}, and so on till the last room where n_{iM} of them are turned on for time t_{iM}. The power rating on this fixture however is obviously the same across all rooms, so all $P_{ij} = P_i$. From the knowledge of the above data, we can say that the energy consumed by the lights of type L_i is

$$E_i = \sum_{j=1}^{M} n_{ij} \cdot P_{ij} \cdot t_{ij}$$

If there are K different types of such fixtures, then the total energy consumed by all types of light fixtures can be given by the expression

$$\boxed{E = \sum_{i=1}^{K} E_i = \sum_{i=1}^{K} \sum_{j=1}^{M} n_{ij} \cdot t_{ij} \cdot P_{ij}} \tag{1}$$

Unfortunately, this form of the total energy expression doesn't look like something which can be written as a generic matrix multiplication. However, the `numpy` library of Python allows us to do entry-wise multiplication of matrices, and sum over all the entries, which is precisely what we require here. This operation is summarized in the in the equation below

$$\begin{bmatrix} n_{1,1} & n_{1,2} & \cdots \\ n_{2,1} & n_{2,2} & \cdots \\ \vdots & \vdots & \ddots \end{bmatrix} \star \begin{bmatrix} t_{1,1} & t_{1,2} & \cdots \\ t_{2,1} & t_{2,2} & \cdots \\ \vdots & \vdots & \ddots \end{bmatrix} \star \begin{bmatrix} P_{1,1} & P_{1,2} & \cdots \\ P_{2,1} & P_{2,2} & \cdots \\ \vdots & \vdots & \ddots \end{bmatrix} = \begin{bmatrix} n_{1,1}\, t_{1,1}\, P_{1,1} & n_{1,2}\, t_{2,1}\, P_{2,1} & \cdots \\ n_{2,1}\, t_{2,1}\, P_{2,1} & n_{2,2}\, t_{2,2}\, P_{2,2} & \cdots \\ \vdots & \vdots & \ddots \end{bmatrix}$$

$$\implies \text{sum} \begin{bmatrix} n_{1,1}\, t_{1,1}\, P_{1,1} & n_{1,2}\, t_{2,1}\, P_{2,1} & \cdots \\ n_{2,1}\, t_{2,1}\, P_{2,1} & n_{2,2}\, t_{2,2}\, P_{2,2} & \cdots \\ \vdots & \vdots & \ddots \end{bmatrix} = \sum_{i=1}^{K} \sum_{j=1}^{M} n_{ij} \cdot t_{ij} \cdot P_{ij} = \sum_{i=1}^{K} E_i = E$$

4 Data collection

Before we start with the analysis, we have to collect our data and structure it in the form of a table which is similar in structure to the matrix that we want to construct out of our data.

The data was primarily collected from two buildings of the campus - the hostels, and the ABs. More precisely, we collected the data for one hostel (Hostel 5, and some rooms of Hostel 7) and the 5th floor of AB-2. Once we have this data, we can multiply the data for the hostels by 4 (number of hostels), and for the ABs by 5 (number of floors) $\times$ 2 (number of ABs) = 10 to get an estimate for both the buildings.

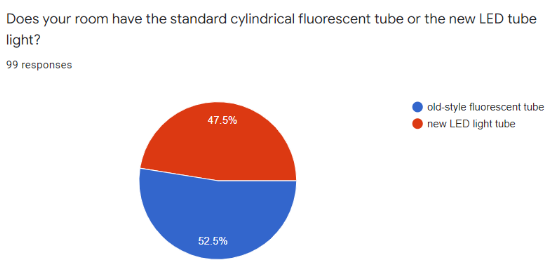
Most of the data was collected via site visits and doing offline surveying; however, a lot of important data was also obtained from online survey forms that were sent to the `students@iisermohali.ac.in` and `faculty@iisermohali.ac.in` mailing lists for the student and faculty surveys, respectively. Around 99 students and 14 faculty members filled up these forms.

4.1 Count data

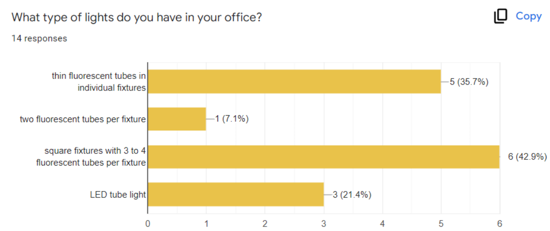
The count data for the hostels and the ABs is given in this subsection.

The data for the tubelights T and LEDs L installed in hostel rooms was obtained via the survey forms filled by students. It was found out that around 52% still have the old fluorescent tubelights installed in their rooms whereas 48% have the new LEDs. It was also found out from the survey that the average number of hours that a student used the balcony light was ≈ 0.15 hours; therefore, we have excluded the balcony lights from the analysis since their contribution is negligible.

From the faculty survey, it was found out that on an average, a faculty office had 3.44 H^2 (2$\times$ halogen fixtures), 1.72 T (tubelights) and 0.84 L (LED tubes) and after multplication by the number of offices, we get some sensible numbers for the count of these lights.



(a) Student survey on the type of light in their hostel rooms.



(b) Faculty survey on the type of lights in their offices.

Figure 2: Data obtained from survey forms.

	T^4	H^2	T	D	L	ℓ	α^2	U	C_9	C_{13}
1st Floor Corridor	4	0	4	26	0	26	0	0	0	0
2nd (3rd) Floor Corridor	8	0	0	72	8	0	0	0	0	0
4th Floor Corridor	4	0	0	32	4	4	0	0	0	0
5th Floor Corridor	4	0	0	30	0	16	0	0	0	0
6th (7th, 8th) Floor Corridor	12	0	0	78	0	36	0	0	0	0
Mess H7	0	0	2	0	8	0	0	0	0	0
Mess H5	4	0	2	0	4	0	0	0	0	0
Study Rooms	26	0	6	0	14	0	0	0	0	0
Study Room Corridor	0	0	4	2	0	2	0	0	0	0
Washroom	0	0	0	0	0	48	0	144	672	0
Rooms	0	0	248	0	274	0	0	0	0	524
Total	62	0	266	240	312	132	0	144	672	524

Table 1: Count table n_{ij} for the Hostels.

	H^2	T	L	α^2	U
Faculty Office	412.8	206.4	100.8	0	0
Faculty Corridor	0	0	30	90	0
Washrooms	0	20	0	0	40
n-TL	520	0	40	0	0
n-L	400	0	160	0	0
Corridor general	0	0	130	360	0
Staircases	0	0	20	0	0
Lift Area	10	0	0	0	0
Total	1343	226	481	450	40

Table 2: Count table n_{ij} for the ABs.

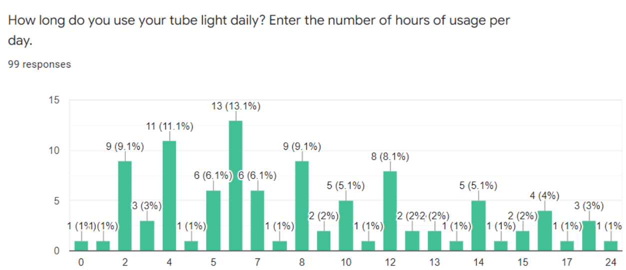
The final data is collated above in the Tables 1 and 2 and is the estimate obtained after multiplying the data for hostels and ABs by 4 and 10 respectively. One can see that some of the values have a fractional component in the tables. A fractional component in the count is generally a result of data obtained by averaging over a smaller sample i.e. via a survey. Howver, we have rounded off all the fractional values in the Total to the nearest integers.

4.2 Time data

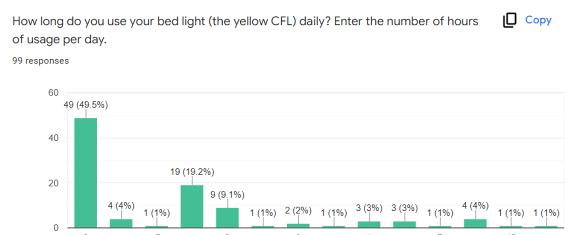
The time data (i.e. the time for which the fixtures of light in a particular location were switched on) for the hostels and ABs is provided in this subsection. The data is shown in the Tables 3 and 4.

The data for time was obtained by both via online feedback form surveys as well as surveying people offline. From the student survey form, it was found out that the T/L (tubelight/LED) fixture is switched on for around 8.25 hours per day, and the yellow reading CFL C_{13} is used for around 1.6 hours a day.

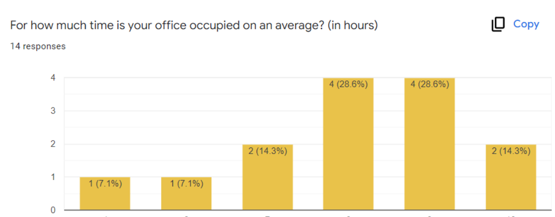
Simiarly, from the faculty surveys, it was found out that the faculty offices are occupied for around 8 hours daily on average, and so we use that as the time for which the lights are also switched on.



(a) Student survey on the T/L (tubelight/LED) usage time.



(b) Student survey on the C_{13} reading light usage.



(c) Faculty survey on the occupation hours of their office.

Figure 3: Data obtained from survey forms.

	T^4	H^2	T	D	L	ℓ	α^2	U	C_9	C_{13}
1st Floor Corridor	12	0	12	12	12	12	0	0	0	0
2nd (3rd) Floor Corridor	12	0	12	12	12	12	0	0	0	0
4th Floor Corridor	12	0	12	12	12	12	0	0	0	0
5th Floor Corridor	12	0	12	12	12	12	0	0	0	0
6th (7th, 8th) Floor Corridor	12	0	12	12	12	12	0	0	0	0
Mess H7	9	0	9	0	9	0	0	0	0	0
Mess H5	9	0	9	0	9	0	0	0	0	0
Study Rooms	16	0	16	0	16	0	0	0	0	0
Study Room Corridor	12	0	12	12	12	12	0	0	0	0
Washroom	0	0	0	0	0	24	0	24	24	0
Rooms	0	0	8.25	0	8.25	0	0	0	0	1.6

Table 3: Time table t_{ij} for the Hostels.

	H^2	T	L	α^2	U
Faculty Office	8	8	8	8	8
Faculty Corridor	16	16	16	16	16
Washrooms	24	24	24	24	24
n-TL	20	20	20	20	20
n-L	20	20	20	20	20
Corridor general	16	16	16	16	16
Staircases	8	8	8	8	8
Lift Area	8	8	8	8	8

Table 4: Time table t_{ij} for the ABs.

The time data collected is in units of *hours*. As always, wherever there are fractional values for the time, the data is obtained via averaging over a sample that was collected.

4.3 Power rating data

Finally, the power ratings of the various light fixtures present throughout the campus are provided in this subsection. The data for the power ratings of the light fixtures was obtained from the help of the course instructor Prof. Baerbel Sinha, and the H-5 caretaker Mr. Brijesh.

The data for the power ratings of the light fixtures in hostels and ABs is given in Tables 5 and 6. As mentioned before, since the power ratings are independent of location of the fixture, the power rating table (matrix) is constant along the columns.

	T^4	H^2	T	D	L	ℓ	α^2	U	C_9	C_{13}
1st Floor Corridor	72	72	28	11	18	9	22	20	9	13
2nd (3rd) Floor Corridor	72	72	28	11	18	9	22	20	9	13
4th Floor Corridor	72	72	28	11	18	9	22	20	9	13
5th Floor Corridor	72	72	28	11	18	9	22	20	9	13
6th (7th, 8th) Floor Corridor	72	72	28	11	18	9	22	20	9	13
Mess H7	72	72	28	11	18	9	22	20	9	13
Mess H5	72	72	28	11	18	9	22	20	9	13
Study Rooms	72	72	28	11	18	9	22	20	9	13
Study Room Corridor	72	72	28	11	18	9	22	20	9	13
Washroom	72	72	28	11	18	9	22	20	9	13
Rooms	72	72	28	11	18	9	22	20	9	13

Table 5: Power rating table P_{ij} for the Hostels.

	H^2	T	L	α^2	U
Faculty Office	72	28	18	22	20
Faculty Corridor	72	28	18	22	20
Washrooms	72	28	18	22	20
n-TL	72	28	18	22	20
n-L	72	28	18	22	20
Corridor general	72	28	18	22	20
Staircases	72	28	18	22	20
Lift Area	72	28	18	22	20

Table 6: Power table P_{ij} for the ABs.

The power ratings data in the tables is given in units of *Watts (W)*.

5 Analysis

Once we have the the count, time and the power data in form of the required format, we can interpret them as matrices and do an entry-wise multiplication of the three matrices. We denote this entry-wise matrix multiplication by the operation $\star$. So the energy consumption is calculated as

$$E = \text{sum}(\mathbf{n} \star \mathbf{P} \star \mathbf{t})$$

The above algorithm is implemented computationally using the `numpy` library in Python. The entry-wise multiplication is achieved with the function `numpy.multiply(matrix_a, matrix_b)` and the sum over all the entries is obtained via the function `numpy.sum(matrix)`.

5.1 Energy consumption calculation

5.1.1 Energy consumption due to lights in Hostels

On doing an entry-wise mutiplication of the matrices in Tables 1, 3, and 5 and then taking the sum over all entries, the estimate for energy consumption in the hostels due to lights comes out as

$$E_{\text{Hostels}} = \text{sum}[(\mathbf{n} \star \mathbf{P} \star \mathbf{t})_{\text{Hostels}}] \approx 898 \text{ kWh/day}$$

5.1.2 Energy consumption due to lights in ABs

Similarly, performing an entry-wise mutiplication of the matrices in Tables 2, 4, and 6 and then taking the sum over all entries, the estimate for energy consumption in the ABs due to lights comes out as

$$E_{\text{AB}} = \text{sum}[(\mathbf{n} \star \mathbf{P} \star \mathbf{t})_{\text{AB}}] \approx 1941 \text{ kWh/day}$$

5.2 Energy consumption after replacement drive

The above calculations for the energy consumption in hostels and ABs was performed according to the current scenario of infrastructure in IISER Mohali. We now aim to explore what would happen if we propose a replacement drive to phase out inefficient tubelights, halogen tubes, and CFLs and substitute them with newer LEDs which provide same or higher luminous flux with significantly reduced energy consumption.

The only change that we need to introduce in the calculations is to modify the power rating matrix with the new matrix having the power ratings of efficient alternatives i.e. $P_{ij} \to \widetilde{P}_{ij}$. Following is the change that we propose in a LED replacement drive such that approximately the same luminosity flux is maintained -

- Replace T^4 and H^2 with $2 \times L$.
- Replace T with L.
- Replace C_9 and α^2 with m.
- Replace D, U, and C_{13} with ℓ.

Let's now calculate the effects of such a replacement drive.

5.2.1 Energy consumption due to lights in Hostels after replacement drive

Modifying the $\mathbf{P} \to \widetilde{\mathbf{P}}$ while keeping the $\mathbf{n}$ and $\mathbf{t}$ matrix to be the same, we get the reduced energy consumption for the hostels as

$$\widetilde{E}_{\text{Hostels}} = \text{sum}\Big[(\mathbf{n} \star \widetilde{\mathbf{P}} \star \mathbf{t})_{\text{Hostels}}\Big] \approx 569 \text{ kWh/day}$$

The energy savings in the hostels can be calculated by subtracting the energy consumption after the drive from energy consumption before the drive

$$\Delta E_{\text{Hostels}} = E_{\text{Hostels}} - \widetilde{E}_{\text{Hostels}} \approx 329 \text{ kWh/day}$$

5.2.2 Energy consumption due to lights in ABs after replacement drive

Modifying the $\mathbf{P} \to \widetilde{\mathbf{P}}$ while keeping the $\mathbf{n}$ and $\mathbf{t}$ matrix to be the same, we get the reduced energy consumption for the ABs as

$$\widetilde{E}_{\text{AB}} = \text{sum}\Big[(\mathbf{n} \star \widetilde{\mathbf{P}} \star \mathbf{t})_{\text{AB}}\Big] \approx 1002 \text{ kWh/day}$$

The energy savings in the ABs can be calculated by subtracting the energy consumption after the drive from energy consumption before the drive

$$\Delta E_{\text{AB}} = E_{\text{AB}} - \widetilde{E}_{\text{AB}} \approx 938 \text{ kWh/day}$$

5.3 Energy consumption and savings for the entire campus

In the previous subsections, we have successfully calculated the energy consumption and the savings as a result of a hypothetical LED replacement drive. But these calculations were only done for the hostels and ABs since that is the only data we have. Therefore, naturally, we would wish to extrapolate the energy consumption and savings results to the entire campus.

Fortunately, we have the data for the total energy consumption (not just due to lights) for the various buildings of IISER Mohali which was provided by Prof. Baerbel Sinha. A pie chart distribution of the distribution of energy consumption across various buildings is shown in Fig. 4.

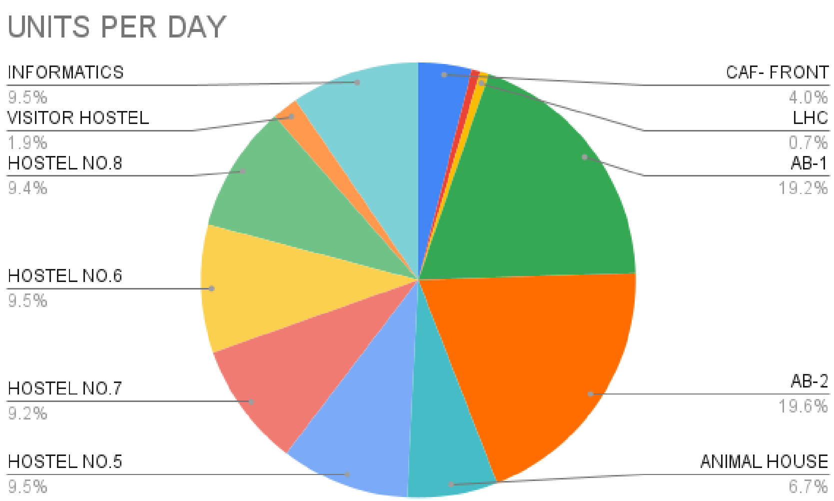


Figure 4: Distribution of total energy consumption across campus (Jan - Feb 2022 data).

If we sum up the contributions of all the hostels and both AB-1 and AB-2 separately, we see that the hostels are responsible for 37.6% and ABs are responsible for 38.8% of the total energy consumption in the campus.

Location	Units per day
CAF	998
Admin Block	160
LHC	166
AB-1	4829
AB-2	4932
Animal Facility	1688
Hostel 5	2400
Hostel 7	2323
Hostel 6	2392
Hostel 8	2371
Visitor Hostel	480
Informatics	2400
Total	**25139**

Table 7: Total energy consumption chart for Jan-Feb 2022.

Now this creates a problem while extrapolating the energy consumption due to lights because the fraction of energy consumption due to lights is different for Hostels and ABs. Does $\sim 38\%$ of total energy consumption $\implies$ 898 kWh/day or 1941 kWh/day of consumption due to lights? Clearly, the percentage of consumption due to lights is different in both the buildings.

- For the hostels, the percentage of consumption due to lights is around $E_{\text{Hostels}}/E_{\text{Total, Hostels}} = 898/(2400 + 2323 + 2392 + 2371) \approx \mathbf{9.46}\%$.
- For the ABs, the percentage of consumption due to lights is around $E_{\text{AB}}/E_{\text{Total, AB}} = 1941/(4829 + 4932) \approx \mathbf{19.89}\%$.

Therefore, we have to extrapolate our results carefully. One of the ways is to do a weighted extrapolation. We define a weighted extrapolation (in our context) as follows -

- The fraction of energy consumption in Visitor Hostel, LHC, and Admin Block would be similar to hostels since VH is a residential building, and neither LHC nor Admin Block have any heavy load equipment that is usually present in AB labs . Therefore, we'll assume that the percentage of energy consumption due to lights in VH, LHC and Admin Block is $\approx 9.46\%$.
- Similarly, the fraction of energy consumption in CAF, Animal Facility, and Informatics would be similar to ABs since all of these locations also have some high energy consumption equipment present in them. Therefore, we'll assume that the percentage of energy consumption due to lights in CAF, Animal Facility and Informatics is $\approx 19.89\%$.

Therefore, we can extrapolate our energy consumption due to lights of the entire campus in a weighted manner as follows

$$E_{\text{lights}} = E_{\text{Hostel}} + E_{\text{AB}} + 0.0946 \cdot (E_{\text{Total, VH}} + E_{\text{Total, LHC}} + E_{\text{Total, Admin Block}}) \\ + 0.1989 \cdot (E_{\text{Total, CAF}} + E_{\text{Total, AF}} + E_{\text{Total, Inf}})$$

Substituting in the values of E_{Total} of different buildings, we get an estimate of the energy consumption due to the lights as

$$\boxed{E_{\text{lights}} \approx 3926 \text{ kWh/day}} \tag{2}$$

which comes out as around $\approx 15.6\%$ percent of the total electricity consumption on campus.

To calculate the savings in electricity consumption throughout the campus after a replacement drive, we can still use a similar weighted extrapolation assuming the percentage of savings in similar buildings is similar. Essentially, we are assuming that the savings are proportional to the total energy consumption and this proportionality constant is the same across similar buildings - {Hostels : VH, LHC, Admin Block}, {AB : CAF, Animal Facility, Informatics}.

- The percentage of savings in Hostels is $\Delta E_{\text{Hostels}}/E_{\text{Total, H}} \approx 3.47\%$.
- The percentage of savings in AB is $\Delta E_{\text{AB}}/E_{\text{Total, AB}} \approx 9.6\%$.

Therefore, the total savings can again be estimated using the weighted extrapolation

$$\Delta E_{\text{lights}} = \Delta E_{\text{Hostel}} + \Delta E_{\text{AB}} + 0.0347 \cdot (E_{\text{Total, VH}} + E_{\text{Total, LHC}} + E_{\text{Total, Acad Block}}) \\ + 0.096 \cdot (E_{\text{Total, CAF}} + E_{\text{Total, AF}} + E_{\text{Total, Inf}})$$

Substituting in the values of E_{Total} of different buildings, we get an estimate of the energy savings if we carry out the replacement drive

$$\boxed{\Delta E_{\text{lights}} \approx 1783 \text{ kWh/day}} \tag{3}$$

From the website of Punjab State Electricity Regulatory Commission (PSERC), under the guideline SVI.1.2, the government colleges are required to pay the tariff for domestic supply [10]. From the tariff ratecard [11], it was found out that we pay around ₹ 8.1/kWh. Therefore, we can estimate the economic savings if we switch to LED alternatives, and it comes out to be around

$$\boxed{\text{Savings} = 1783 \times 8.1 \approx ₹\, 14,500/\text{day}} \tag{4}$$

5.4 Estimated Cost of the replacement drive

Although we estimated that using LEDs can lead to enourmous economic benefits, we haven't really factored in the *initial cost of investment* into the LED alternatives. This is essential because the monetary benefits will only be useful if the LED alternatives have a manageable investment cost and if the payback period is short enough.

If we go forward with the proposal of replacements as proposed in subsection 5.2, then using the data from the tables 1 and 2, we will need

- $(62 \times 2 + 266) = \underline{390\ L}$, $\underline{672\ m}$, and $(524 + 144 + 240) = \underline{980\ \ell}$ LED fixtures in Hostels.
- $(1343 \times 2 + 226) = \underline{2912\ L}$, $\underline{450\ m}$, and $\underline{40\ \ell}$ LED fixtures in ABs.

Again, we only have the raw data for hostels and ABs. To get an estimate of the total LED replacements, we will again to a weighted extrapolation assuming that the number of replacements is proportional to the total electricity consumption and this proportionality constant is the same across similar buildings - {Hostels : VH, LHC, Admin Block}, {AB : CAF, Animal Facility, Informatics}.

- The ratio of the number of L's, ℓ's, and m's to the total energy consumption of the hostels is
  - $(\#\text{ of } L)/E_{\text{Total, H}} = 0.041$.
  - $(\#\text{ of } \ell)/E_{\text{Total, H}} = 0.103$.
  - $(\#\text{ of } m)/E_{\text{Total, H}} = 0.071$.
- The ratio of the number of L's, ℓ's, and m's to the total energy consumption of the ABs is
  - $(\#\text{ of } L)/E_{\text{Total, AB}} = 0.298$.
  - $(\#\text{ of } \ell)/E_{\text{Total, AB}} = 0.004$.
  - $(\#\text{ of } m)/E_{\text{Total, AB}} = 0.046$.

Therefore, an estimate of the different types of lights that would be required in a replacement drive are as follows

$$(\#\text{ of } L) = (\#\text{ of } L)_{\text{Hostel}} + (\#\text{ of } L)_{\text{AB}} + 0.041 \cdot (E_{\text{Total, VH}} + E_{\text{Total, LHC}} + E_{\text{Total, Acad Block}}) + 0.298 \cdot (E_{\text{Total, CAF}} + E_{\text{Total, AF}} + E_{\text{Total, Inf}})$$

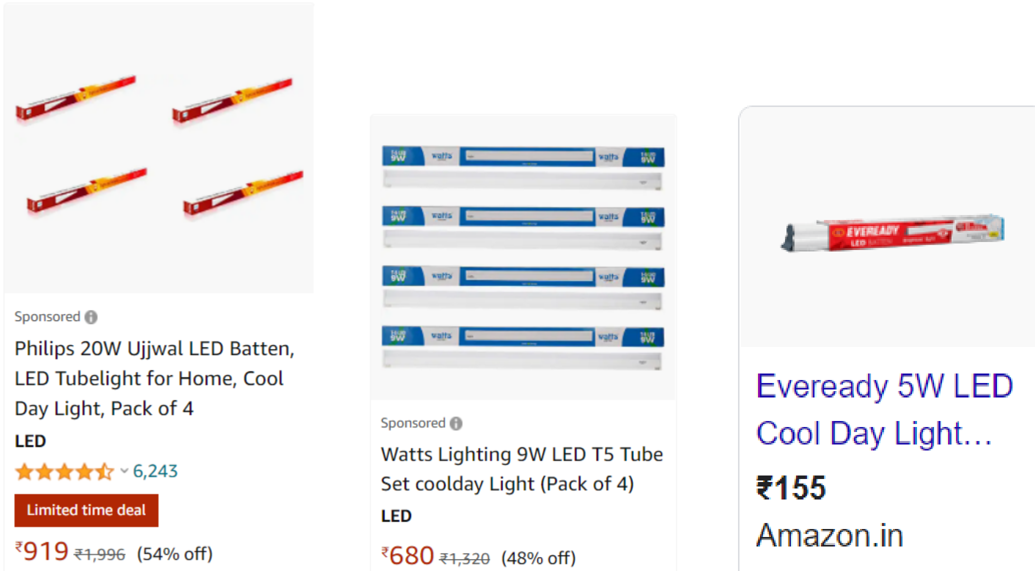
$$(\#\text{ of } \ell) = (\#\text{ of } \ell)_{\text{Hostel}} + (\#\text{ of } \ell)_{\text{AB}} + 0.103 \cdot (E_{\text{Total, VH}} + E_{\text{Total, LHC}} + E_{\text{Total, Acad Block}}) + 0.004 \cdot (E_{\text{Total, CAF}} + E_{\text{Total, AF}} + E_{\text{Total, Inf}})$$

$$(\#\text{ of } m) = (\#\text{ of } m)_{\text{Hostel}} + (\#\text{ of } m)_{\text{AB}} + 0.071 \cdot (E_{\text{Total, VH}} + E_{\text{Total, LHC}} + E_{\text{Total, Acad Block}}) + 0.046 \cdot (E_{\text{Total, CAF}} + E_{\text{Total, AF}} + E_{\text{Total, Inf}})$$

This gives the following estimates

- $(\#\text{ of } L) \approx 4850$.
- $(\#\text{ of } \ell) \approx 1123$.
- $(\#\text{ of } m) \approx 1413$.

By going through the internet and looking at the prices of LED light fixtures, we came across three moderately priced candidates for L, ℓ and m respectively.



(a) candidate for L. (b) candidate for ℓ. (c) candidate for m.

Figure 5: Potential candidates for replacement lights.

So we approximate our costs for the LED alternatives as

- Cost of $L \approx$ ₹230
- Cost of $\ell \approx$ ₹170
- Cost of $m \approx$ ₹150

Finally, we use this to estimate the cost of the entire replacement drive. The cost is calculated as follows -

$$\boxed{\text{Replacement drive cost} = (230 \times 4850) + (170 \times 1123) + (1413 \times 150) = \text{₹}15,18,360} \quad (5)$$

5.4.1 Payback Period

The payback period is defined as the amount of time it'll take to neutralize the initial investment from the savings that were generated due to our replacement drive.

For our study, the payback period calculation is given by

$$\text{Payback period} = \frac{\text{Replacement Cost}}{\text{Savings/day}} \approx 105 \text{ days}$$

Therefore, the payback period for such a hypothetical replacement drive would be around 3-4 months, which is quite reasonable.

6 Carbon footprint due to lights

Apart from the monetary benefits that a LED replacement drive has to offer, there are also environmental benefits which can motivate the competent authorities to take appropriate actions.

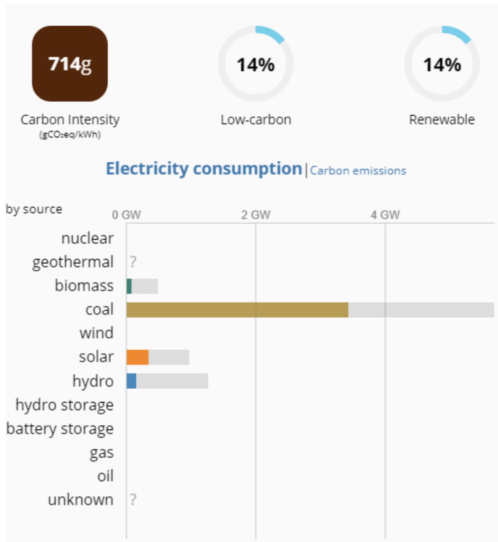


Figure 6: Carbon footprint due to energy generation in Punjab [12].

The energy consumption due to the lights in campus was estimated in the previous subsection and is shown in equation 2. To get the *carbon footprint generated due to lights per day*, we simply multiply the energy by the carbon intensity to get

$$\underline{\text{Carbon footprint due to lights}} = 714 \text{ g CO}_2\text{eq/kWh} \times 3926 \text{ kWh/day} = \boxed{2803.16 \text{ kg CO}_2\text{eq/day}}$$

Similarly, using the value obtained for the savings in energy consumption due to the replacement drive (which was obtained in equation 3), the calculated *carbon footprint reduction that can be accomplished due to the intervention* is

$$\underline{\text{Carbon footprint reduction}} = 714 \text{ g CO}_2\text{eq/kWh} \times 1783 \text{ kWh/day} = \boxed{1273.06 \text{ kg CO}_2\text{eq/day}}$$

7 Summary

As has been stated multiple times throughout the text of this term paper, the calculations presented here are merely an order of magnitude "estimate". We have made a lot of assumptions about the ways in which energy is consumed throughout various locations in the campus, and have derived our estimates using plenty of extrapolation.

Through this term paper, we showed that the current energy consumption in our campus is indeed very high due to some particularly old type of light fixtures which consume a huge amount of electricity, and have the potential to be replaced by much efficient alternatives. Our aim was to do some estimate calculations and see if such a replacement drive was feasible or not, and if it can result in significant monetary as well as environmental benefits.

Through the analysis presented in Section 5, we have shown that if we were to carry a hypothetical replacement drive, it would only take about 3-4 months to cover the initial investment cost using the savings from the electricity bill. Therefore, the monetary incentives are plenty if we plan out this intervention method.

Finally, we have also presented a calculation that shows that we can remove around 1300 kg CO_2 equivalent carbon emissions per day if we switch to the LED alternatives.

We have certainly not touched upon many of the other social effects of this intervention method, most importantly the amount of waste generated in a replacement drive. However, we tried to keep our scope limited throughout this report and have tried to provide a quantitative idea assuming a minimal number of complications, and the social side of this project is left for future exploration.

Raw data and code

The data analysis performed in this project was done using Python 3.9.7, and the raw data (from online and offline surveys) as well as the code for this project are available on the following GitHub repository : `https://github.com/kunal1729verma/HSS636-Term-Paper`.

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