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Electrical Energy Conservation Model using Linear Programming

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ABSTRACT: Over the past few decades each and every organization, be it an industry for production, a unit of manufacturing, a government organization, a limited corporation, a banking sector or an educational institution is focusing on increasing profit margin. And in order to do that, one of the key factors is achieving maximum output with minimum resources (input). Therefore, it has become extremely important for organizations to plan the use of resources in the most optimum way.

I. INTRODUCTION

In this research, Linear Programming has been used to optimize the use of resources. Resources can be anything that act as an input. They can be men, material, money or other assets that can be used by an organization or an individual in order to function effectively. There are laws available in linear programming that are very effective in optimizing the resources. They have been used in this research and electrical energy has been tested and tried to optimize. The results have been further compared with the existing system to provide a proper insight on whether they can be helpful in creating a proper plan for optimization for an organization.

II. LITERATURE REVIEW

The parameter that has been tried to optimize is the use of energy, especially electricity that is also been used in large volumes inside the educational buildings. With the fact that the commercial rates at which electricity is offered by UPCL Power grid is much higher and eventually leads to a very high bill. So in order to minimize the cost, the entire system of electricity is being replaced with Solar Cells. Although Solar Cells are a very efficient and cost effective method that can completely replace the existing electricity usage system, however the installation cost is higher than its counterpart. Therefore, keeping in mind the budget constraints, a model has been formed, that will also calculate the repayment period of the installation cost. Further all the CFLs have been replaced by LEDs in order to further maximize the profit.

In the literature survey it has been found that almost all the developing countries are highly energy dependent and are purchasing more than 60% of energy. According to a report cited in the reference section, around 86% of the energy requirement of this world will be able to be completed by the year 2035. And as it is known that organizational and commercial buildings use a very large amount of electrical energy, therefore working towards a change in system may prove highly beneficial. Not only will it save cost for the owner of the firm, but will help in developing the economy of the country and will support towards a greener world.

If the model turns out to be success and is adopted for use, it can save a good amount of energy. Imagine if, all the major electricity consumption centers and offices are replaced with the new solar system, it will turn out to be a boon to mankind, and the need for electrical energy will get reduced to less than half of what is required now.

Use of Linear Programming in solution

In around last 65 years linear programming has been used extensively in military, financial, industrial, accounting, marketing and agricultural sectors. Although these are all diverse sectors, Linear Programming can be used to solve them. All linear programming questions have four properties in common.

All the linear programming questions either maximize or minimize some quantity, they can be profit or cost. We usually call this property as the ***Objective Function*** of a linear programming question. The major concern for any manufacturing organization can be to maximize the profit. In case of any financial or military sector the concern can be to reduce the cost. Whatever the case may be, the Objective function has to be clearly written and stated [2].

The second property that any linear programming question has in the presence of ***constraints*** or restrictions [3]. That is to say it is the limit to which we can pursue the objective. Like, in any production company, the production can be limited by number of assembly lines or availability of manpower. Therefore, after the second property, we can state that maximization or minimization of a quantity subject to the limited resources.

There should be ***alternative course of actions***. One or more alternative solutions to the problem in question must be available. So that we have options to choose from. If no alternative option is available, we will not need linear programming. Linear programming is all about choosing the best.

The objective and the constraints in any linear programming question should be ***expressed in terms of a linear equation***. By saying linear equation what is meant to be said that the equation should be a first order equation. Like, $2A + 4B = 8$ or $3A + 7B \geq 16$ are acceptable equations, however, $3A^2 + 4B^3 + 5AB = 24$ is not an acceptable equation because it has A^2 and also B^3 and then AB as terms in it. None of such can be included in a linear programming equation.

Apart from the above mentioned four properties, there are also some assumptions that need to be made while formulating a linear programming question. They are: certainty, proportionality, additivity, divisibility, non-negative variables. We should be certain that objectives and constraints are certain, that is they do not change with time. All the variables are in exact proportions. The total of all the objectives and constraints can be added and are divisible. Also, none of the objective or constraint is a negative number, as they all are real values and cannot be negative in any case.

Using all of these properties and assumptions a linear programming problem has to be formulated. Only then can a reliable solution be expected out of the solution. During this entire thesis, all these properties and assumptions have been kept in mind while formulating a problem.

All the three input variables considered to be essential resources have been formulated into objective functions and all the constraints have been duly considered. The alternatives have been studied and then linear equation has been formed to solve each and every case in the problem. An individual model has been formed for each case.

To solve a Linear Programming equation, we will be using a software called Linear Program Solver (LiPS) v1.11.1. It is an optimization package used for solving linear programming models. It has the capability to solve all kinds of problems such as Maximization problems, Minimization problems, integer problems, goal problems etc. It takes the optimization equation, variables and constraints as the input and generates the optimum solution as the output. It can also draw graphs for the output.

Some notable features of the program are:

- The program is based on efficient implementation of the modified simplex method that is specifically designed to solve large scale problems.
- It provides not only an answer to the problem but also a detailed solution process as a sequence of simplex tables, so that it can also be used for teaching learning purposes of linear programming.
- It provides the sequence of sensitivity analysis, which enable us to study the behavior of the model when the parameters are changed. They include changes in coefficient of the objective function, changes in variables, changes in constraints, changes in rows and columns of matrices etc.
- It also supports goal programming which supports weighted and Lexicography GP methods. Goal programming methods are intended for solving multi-objective optimization problems.

III. RESOURCE UNDER OBSERVATION

Electrical Energy Conservation

Energy conservation is one of the major concerns for an organization. In this report, energy conservation will focus on minimizing the consumption of electricity.

Various methods and materials can be used for reduction in expenditure incurred over electricity every year. Samar Jaber and Salman Ajib [7, 16] highlighted the main terms to conserve energy in buildings. The major points shown and discussed by them have been summarized below:

1. The building should be designed considering climatic effects i.e. to decrease heat, cooling, sparking in wires and appliances etc.
2. To improve the quality of the electrical equipment and appliances being used in the building.
3. Initiating a change and then completely replacing the non-renewable with the renewable and cheaper available sources.

Here, we will try to calculate the savings per year if three major electricity consumption area are replaced with their cost efficient counterparts. The three major area of our concern will be:

1. Installing of Solar Panels and reducing the electricity bills
2. Replacing all the CFL and tube lights with LED lights.

Moving ahead, a model will be created that will provide an insight and comparison of how energy along with cost can be saved by replacing some of the majorly used electric equipment.

Data Accumulation

As already briefed earlier, we will here try to replace some of the major electricity consumption areas in order to bring down the cost and energy usage.

A. Solar Energy: The first and major task is to replace the electricity consumption from power grids with solar energy. Solar energy is a clean and quality energy source in the list of renewable energy sources. It is stored in solar panels also known as solar cells that can be further used in any day to day activities where in electricity is being consumed. Therefore, we need to install a high quality solar panel which can store a large amount of thermal energy and for a longer duration. The principal of working of a solar panel is as follows: When the solar light falls on the panel, it converts it into electric energy and then further stores it in cells (a.k.a. batteries), that can be further converted into a.c. power and used as a supply to any electric equipment. The installation of solar panels are also easy. They can be installed at any open space. Rooftops are the best place for utilization of space as well as they get direct sunlight. So a good amount of light and heat can fall on the panel for a very long time [21].

Working of a Solar (Photovoltaic) cell: The solar energy is in the form of light, which is further made up of photons. The photovoltaic cells are actually diodes where in electrons and holes are in majority in n- and p-regions respectively. These electron and holes combine to form an electron-hole pair (e.h.p.). When a photon is incident on an e.h.p., it transfers its energy to the e.h.p, which disintegrates and further splits into individual electrons and holes. The photovoltaic cell is supported by an external voltage V, which acts under the forward bias condition. Due the effect of the forward bias, the spit electron and hole experience a drift towards their own region *i.e.* n- and p-regions respectively. As a result of their drift, a current is generated that can be immediately stored in the cell situated next to it. This stored electrical energy can be further used for any purpose where electric consumption is required. For higher gains, we can connect a number of photovoltaic cells in series and a module can be formed. Many modules can be further connected to form a panel. Many panels can be placed together to form an array that can be sufficiently large to provide electricity to the entire building with different consumptions.

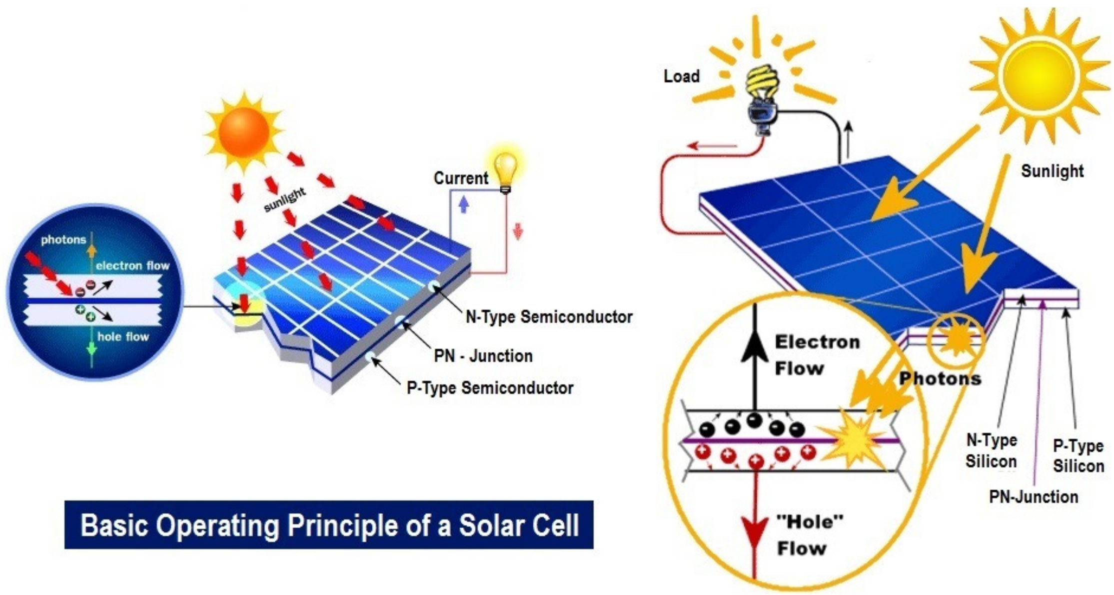

Fig. 1. Working of a Solar Cell [12].

These solar cells can be installed in any open space where a good amount of heat and light can fall on them. In order to save space, rooftops have been found to be the best place for this purpose. Even the entire roof can be covered with solar panels that can be very effective and efficient in saving money being used in purchasing electricity [19]. Solar cells are a good substitute for the grid electricity, however there are some disadvantages of electricity through solar energy. The major disadvantage is that the solar panels are very expensive and needs a one-off payment. In other words the installation cost is high. Another disadvantage of solar energy is the deficiency of sunlight at certain times of the day, month and year. Light from the Sun may vary a lot during rainy seasons, or in winters due to high fog or sometimes in other times of the year due to bad weather conditions. Also, the charging of the cell will stop at night.

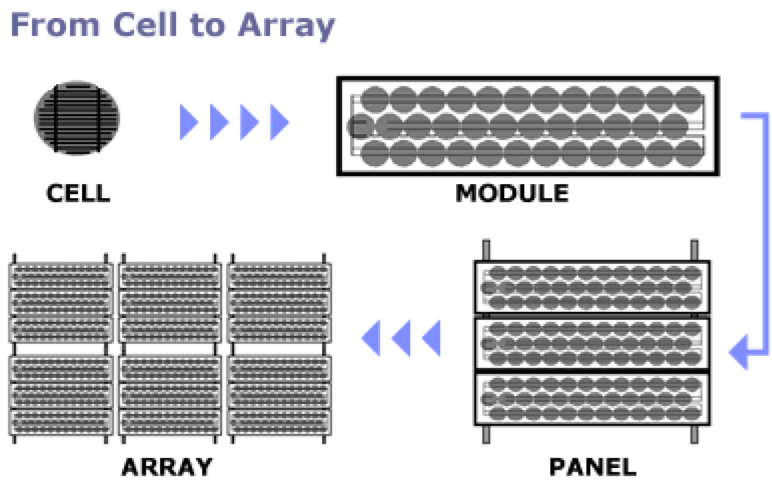

Fig. 2. Solar Cell: From Basic Unit (Cell) to Array [13].

Fig. 3. Rooftop installation of Solar Panel [14].

Types of Solar Panels: Although solar panels are available in a large variety, however, they can be majorly classified into two types:

1. Mono-crystalline Panels
2. Polycrystalline Panels

Mono-crystalline Panels: Mono-crystalline solar panels are also known as Single Crystalline Solar Panels. These panels are made up of Single crystal Silicon. They can be easily identified by their physical appearance. As the Silicon being used in this are high grade Silicon, the color of these panels are generally dark blue. They are made up of sliced Wafers cut from cylindrical Silicon Ingots.

Advantages

- These panels have a high efficiency of more than 20%.
- They require less space
- They have a long life as purest form of Silicon is used in manufacturing of these panels.
- They have an edge in performance over Polycrystalline panels in areas which are cooler.

Disadvantages

- They are costly as Silicon is in the purest form, so the manufacturing cost is very high.
- Partial shading of these panels can lead to a complete power cut-off.

Polycrystalline Panels: Here, different grades of Silicon are mixed together to form the panel. They use Multi-crystalline Silicon. Square wafers are made by melting the raw silicon. Multiple small crystals make a module. The physical appearance of polycrystalline is different from that of Mono-crystalline panels.

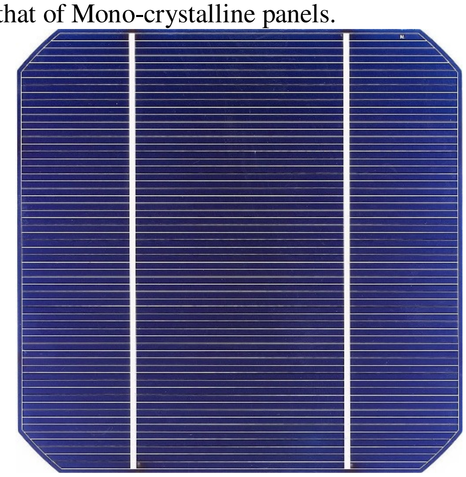

Fig. 4. Mono-crystalline Solar Panel [15].

The bluish shade is much lighter and they don't have cut edges. They can be commonly used for domestic purposes.

Advantages

- They are cheaper than Mono-crystalline due to lower production cost.
- They have an edge in performance in hot conditions
- Good life span.

Disadvantages

- They are comparatively lesser efficient than their counterpart.
- They require more space for installation.

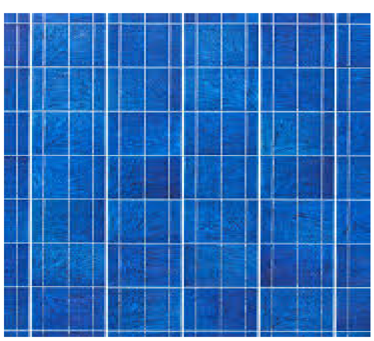

Fig. 5. Polycrystalline Solar Panel [18].

B. Traditional Lights vs. LED Lights: Lights have been a major invention in technology and have been in use since the early seventeenth century. In late 19[th] century, Tube lights were invented which consume much higher power than the LEDs being used today. Also, they had a high maintenance cost, so they were eventually replaced by CFLs. Although CFLs were better and energy efficient compared to Tube Lights and Incandescent bulbs, however, a major improvement was yet to be done. CFLs emit most of the energy in the form of heat. As per a report, around 80-90% of energy from a CFL is wasted as heat, only the remaining energy is converted into light energy that we actually use. Therefore, this was a major concern and a lot of research has been focused on improving the efficiency of electric bulbs. Almost all the countries have made stringent rules to be followed by the citizens of the country in order to save energy as energy consumption has been a major concern for all the countries. Some countries have even banned the usage of incandescent bulbs because of their high electricity consumption.

This as a substance gave way for LED bulbs. LED bulbs are a recent change in technology, but are highly efficient when compared to Incandescent bulbs or CFLs. When a CFL and an LED was bought from market for testing purposes, it was found in the laboratory test that LED uses only 64% of power compared to CFL when test was done with CFL and LED with same illumination. The only disadvantage of LED over CFL is that they are relatively costly, however, considering the lifetime, an LED has a greater lifespan compared to that of a CFL. So, they tend to be comparatively cheaper in the long run. While purchasing any equipment for installation purpose there are many other factors that affect the efficiency. They are power consumption, voltage rating, quality of the product, date of manufacturing, energy consumption etc.

Fig. 6. LED vs CFL.

Further the data that is needed for calculation of power consumption and installation of solar panels are:

1. Building Specifications
2. Cost for solar panel with 1500W power
3. Area required for installation of solar panel

The building that has been taken for reference is the A-Block building of AITS. It is a two story building having 20 rooms, each room of dimension 6m x 7m. The total area is 840 m^2 with 420m^2 in each floor. The solar panel installation will done on the rooftop of the building.

Table 1: Building Specifications.

S. No.	Building Specifications	Quantity
1.	Total area each floor, m^2	420 m^2 (14m x 30m)
2.	Area available on roof top	220 m^2
3.	Rooms in each floor (6m x 7m)	10 (42 m^2 each)
4.	Total rooms in the building	20 (42 m^2 each)
5.	No. of LEDs required / room	4 x 28W
6.	Total LEDs required	80 (4 x 20)

Table 2: Cost for solar panel with 1500W power.

S. No.	Item / Equipment	Price
1.	Inverter	₹ 18,000
2.	Solar Panel	₹ 82,500
3.	Mounting Structure	₹ 2,500
4.	Charge Monitor and controller	₹ 5,000
5.	Cables, Fuses, Switches	₹ 2,500 (Approx.)
6.	Installation and Service cost	₹ 20,000 (Approx.)
7.	Total Cost	₹ 1,30,500 (Approx.)
8.	Average cost / watt	₹ 87 / watt

Area available on rooftop is 220 m^2, whereas required area for installation and permanent functioning of the Photovoltaic cell based solar panel is approx. 7.76 m^2 for 1000W solar panel, 11.64 m^2 for 1500W solar panel and 15.52 m^2 for 2000W solar panel. Also, the point here to be noted is that the number of Solar Panels and number of LED bulbs may vary as per requirements during practical installation.

Data Analysis

Now a comparison of LED and CFL is presented [20]. This has been taken as a reference in further calculations. If all the existing CFLs are replaced by LEDs (Although some tube lights are also installed in some sections and rooms, however for ease of calculation, all the previously installed components have been considered to be CFLs) and electricity from UPCL grid be replaced by solar power electricity, then energy saving per unit usage has been estimated in the table 4. It also shows the increase in installation cost with increase in energy savings. The energy savings can later be converted into savings in run-time cost.

Table 3: Comparison chart between CFLs and LEDs.

Parameter	CFL	LED
Lifespan (hours)	8000	55,000 – 60,000
Transition Time	Takes time to warm up	Turns on instantly
Electricity usage for same intensity of light	30-32 watts	15-20 watts
Heat emission	7.64 kcal/hour	0.88 kcal/hour
Failures	May catch fire, generate smoke and unpleasant odor.	Not at risk
Durability	Made up of glass so not very durable	Durable
Light output (450 lumens)	13 Watts	5 Watts
Light output (2600 lumens)	40 Watts	28 Watts

Table 4: Energy saving per unit usage and installation cost comparison chart.

Equipment	Energy Savings	Cost of installation
LED Light	12 W	₹ 580
Solar Panel (Low Range)	1000 W	₹ 87,000
Solar Panel (Medium Range)	1500 W	₹ 1,30,500
Solar Panel (High Range)	2000 W	₹ 1,74,000

Recovery Period: The recovery period is the time duration in which the installation cost incurred in switching to the new system is paid back as a difference in savings achieved after switching to the new system from the old system. The saving is calculated by converting the power saved per year into cost saved per year. As the building in consideration is a commercial building, therefore, power cost from UPCL Grid has been taken as ₹ 6.5 / unit. The formula for calculating the recovery period (R_P) is:

Recovery Period (R_P) = Annual expenditure budget (A_E) x 1000 (in watts) / [Energy savings (E_S)] x [Number of days in an year] x [Number of hours / day] x [Per unit price of commercial electricity (in kWh)]

$$(R_P) = \frac{(A_E) \times 1000 \text{ (in watts)}}{E_S \times 365 \times 24 \times ₹\ 6.5 \text{ / kWh}}$$

Formulation of LP Problem

Now we will formulate the LP problem and try to solve it using the LiPS v1.11.1 software. The objective is to maximize the energy savings. Therefore, the objective function will be a maximization function. As clearly understood the constraints in this are going to be the annual expenditure budget, solar panel area, and number of LEDs being used.

Therefore the ***Objective function*** will be:

MAX $E_S = (E_{S1} \times X_1) + (E_{S2} \times X_2) + (E_{S3} \times X_3) + (E_{S4} \times X_4)$

Or MAX $E_S = 12X_1 + 1000X_2 + 1500X_3 + 2000X_4$

Subject to:

Constraint 1:

$(CI_1 \times X_1) + (CI_2 \times X_2) + (CI_3 \times X_3) + (CI_4 \times X_4) \leq A_E$

[A_E = Annual Expenditure Budget]

Or $580X_1 + 87000X_2 + 130500X_3 + 174000X_4 \leq$ 2, 50,000

Constraint 2:

$X_1 \leq 80$

[Number of LED lights required]

Constraint 3:

$7.76X_2 + 11.64X_3 + 15.52X_4 \leq 220$

[Area available for solar panel installation on rooftop]

Where:

X_1 – LED Parameter

X_2 – Solar Panel (Low Range) Parameter

X_3 – Solar Panel (Medium Range) Parameter

X_4 – Solar Panel (High Range) Parameter

E_{S1} – Energy Saving in LED

E_{S2} – Energy Saving in Solar Panel (Low Range)

E_{S3} - Energy Saving in Solar Panel (Medium Range)

E_{S4} - Energy Saving in Solar Panel (High Range)

CI_1 – Cost of installation of LED

CI_2 – Cost of installation of Solar Panel (Low Range)

CI_3 – Cost of installation of Solar Panel (Medium Range)

CI_4 – Cost of installation of Solar Panel (High Range)

Optimized Solution to the problem using LiPS Software

In order to find the optimized solution to the Linear Programming problem function stated above, we again use the software "LiPS" – Linear Program Solver v1.11.1.

For the computer solution, we create a new model by clicking on the 'New' and then select 'Table Model'. In the 'Model Parameters', we enter 'Number of Variables' = 4, 'Number of Constraints' = 3, 'Number of Objectives' = 1. Then we set 'Optimization Direction' to 'Maximization'. Following is the screenshot of the entries in the table

	X1	X2	X3	X4		RHS
Objective	12	1000	1500	2000	->	MAX
Row1	580	87000	130500	174000	<=	250000
Row2	1				<=	80
Row3		7.76	11.64	15.52	<=	220
Lower Bound	0	0	0	0		
Upper Bound	INF	INF	INF	INF		
Type	CONT	CONT	CONT	CONT		

Fig. 7. Screenshot of the entries in the table of EECM.

Clicking on the 'Solve' button, solves the function to minimization and finds the optimal solution after 0 iterations.

The maximum energy saved per year in keeping the budget at ₹ 2,50,000 comes out to be 3300.23W rounded to the nearest digit gives us 3300W.

Following is the table of Results found at individual Variables

```
>> Optimal solution FOUND
>> Maximum = 3300.23
```

*** RESULTS - VARIABLES ***

Variable	Value	Obj. Cost	Reduced Cost
X1	80	12	0
X2	0	1000	0
X3	0	1500	0
X4	509/435	2000	0

Fig. 8. Screenshot of the result generated in EECM.

FURTHER DISCUSSIONS

As we can see in the figures above, the X_4 parameter is not an integer, and has a value greater than 1, therefore, it can be interpreted that the Annual Expenditure Budget (A_E) kept for this is more than what is required.

After further calculations, it was found that the optimum values were obtained when the Annual Expenditure Budget (A_E) was reduced to 220400

Here are the screenshots of the modified results:

	X1	X2	X3	X4		RHS
Objective	12	1000	1500	2000	->	MAX
Row1	580	87000	130500	174000	<=	220400
Row2	1				<=	80
Row3		7.76	11.64	15.52	<=	220
Lower Bound	0	0	0	0		
Upper Bound	INF	INF	INF	INF		
Type	CONT	CONT	CONT	CONT		

Fig. 9. Screenshot of the modified entries in the table of EECM.

Following is the table of Results found at individual Variables

```
>> Optimal solution FOUND
>> Maximum = 2960
```

*** RESULTS - VARIABLES ***

Variable	Value	Obj. Cost	Reduced Cost
X1	80	12	0
X2	0	1000	0
X3	0	1500	0
X4	1	2000	0

Fig. 10. Screenshot of the modified result generated in EECM.

So the modified result is as follows:

The maximum energy saved per year in keeping the budget at ₹ 2,20,400 comes out to be 2960W.

Therefore, the optimized result can be found by installing the following parameters:

1. Installing 80 LED Lights
2. Installing 1 High Range Solar Panel of 2000W
3. Saving = 2960W
4. Annual Expenditure Budget = ₹ 2,20,400

Recovery Period (R_P): In order to calculate the recovery period, we will need to use the formula that was discussed above.

Recovery Period (R_P) = Annual expenditure budget (A_E) x 1000 (in watts) / [Energy savings (E_S)] x [Number of days in an year] x [Number of hours / day] x [Per unit price of commercial electricity (in kWh)]

$$(R_P) = \frac{(A_E) \times 1000 \text{ (in watts)}}{E_S \times 365 \times 24 \times ₹\ 6.5 / \text{kW}}$$

Annual expenditure budget (A_E) = ₹ 2,20,400

Energy savings (E_S) = 2960W

Therefore, Recovery Period (R_P) =

$$(R_P) = \frac{220400 \times 1000}{2960 \times 365 \times 24 \times 6.5}$$

= 1.30

The Recovery Period also known as payback period using this model will be **1.30 years**. After that the system will yield profit.

SUMMARY AND CONCLUSION

In the electrical energy conservation model two major changes have been done. One, the electricity supply from UPCL grid has been replaced with solar energy and second, all the existing CFL lights have been replaced with efficient LED lights. The total installation cost for this project is ₹ 2,20,400. However, this saves approx. 2960 W of energy. When the recovery period was calculated it was found that the recovery period is only 1.30 years, *i.e.* after 1.30 years the entire savings in power (watts) converts into savings of money.

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