On Optimizing the budget allocation to maximize the energy savings of a typical household in Tamilnadu - A linear programming approach

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Abstract: Improving energy efficiency in buildings is a major priority worldwide. Due to growing limitations on land use and awareness of sustainability concerns, the building retrofit market has faced increasing opportunities worldwide. This paper presents a linear programming method to maximize the energy savings of a household in Tamilnadu, India. For energy conservation we need to install photovoltaic solar panels, replacing regular windows with double glazed windows, replacing incandescent bulbs with compact fluorescent light bulbs and replacing C-Energy class house hold appliances with A-Energy class ones. The result indicates that installing photovoltaic solar panels is the optimum choice throughout the entire budget range, as a result of the high energy savings opportunity. Lingo software is used to solve the linear optimization.

Keywords: linear programming-energy conservation-optimization-lingo-photovoltaic panels

1 Introduction

The world is ceased with four major priorities as per the United Nations, these are 'Energy security', 'Drinking water', 'Climate change' and 'Poverty'. Efficient use of energy is a very important concept, not only because it favours a more stable economy, but it also helps prevent environmental pollution, and the combination of these two facts is essential for sustainable development [4, 9]. India is a highly populated country in the world, and it is difficult to satisfy power demand all year long by hydro sources alone. It is necessary to interconnect other renewable / alternative energy sources for reliability and consistence power supply. Renewable energy sources offer a viable alternative to the provision of power in rural areas [1]. For thousands of years mankind has tried to improve the energy efficiency of buildings via simple methods such as choosing the ideal geographic location of by using appropriate building and insulating materials depending on the climate. Now a days energy efficiency in residential and commercial buildings have become a common area of interest. In India, the energy efficiency law came in to effect in 2001 and the energy conservation building code came into in 2007[13]. India domestic energy consumption has increased from 80TWh in 2000 to186TWh in 2012, and constitutes 22% of total current electrical consumption (central electricity authority2013). An increase of 400% in the aggregate floor area of buildings and 20 billion m^2 of new building floor area is expected by 2030. Due to constant increase of GDP. Consumer purchasing power is predicted to grow leading to greater use of domestic appliances, consequently household electrical demand is expected to rise sharply in the coming decade. This growth of residential floor space, combined with expectations of improved domestic comfort, will require an increase in electricity production leading a significant escalation in damaging emissions. As energy consumption from residential buildings is predicted to rise by more than eight times by 2050 under the business as usual scenario, it is of vital importance for India to develop energy efficiency strategies focused on the residential sector to limit the current trend of unsustainable escalating energy demand.

The residential building sector is one of the largest consumers of electricity in India. By 2050, India will be home to 1.6 billion people and most of this growth will come from cities, where the residential needs will double. This rapid expansion in construction would require buildings that are less resource intensive yet meets the aspirations of todays growing middle class. In Tamilnadu, the government is planning to build solar-powered green houses for rural poor. It has allotted Rs.1, 080 crore for construction of 60,000 houses.

In this study, linear programming method was used to optimize the allocation of budget in order to maximize the energy savings of a hypothetical household in Tamilnadu, India. Linear programming is a mathematical method for determining a way to achieve the best outcome in a given mathematical model for a list of requirements represented as linear relationships [10]. A linear programming model simply contains an objective function (to be maximized or minimized) and a constraint function. Linear programming method is very convenient tool that it is used extensively to solve and optimize various types of economical and industrial problems. In this model we will be considered energy savings (W) as the objective function and the budget as the constraint function.

2 Energy savings in Buildings

There are two types of buildings, one is heat and cold. These two systems spend a good amount of currency in the household expenditure. Heat systems are of many types as boilers, heat pipes, heater and cooling machines, air conditioner. As we know that air conditioner is very expensive and its installation cost is very high as well. Energy requirement for the building is done by using many transformation and energy requirement can not met by using these type of expensive appliances. So we will use equipment according to energy requirement of the building. We use insulating materials which can prevent heat loss or in other terms save energy for good extent and quality. As we know there is gap between the wall of window and frame so windows are supposed to loss more heat in comparison to the floor. To overcome heat loss problem from the window we can use insulating materials in windows. Windows provide light, warm and ventilation. Energy efficient windows can help minimize heating, cooling and lighting costs.

Double glazed window is having more sufficient insulating material than normal window. Double glazed window is basically a window having two glass slabs. In between these two slabs or glass some inert gas or vacuum can be filled because inert gas like argon is a good insulator of heat. So when the heat ray or sunlight falls on the window then due to that insulating material on the window very less amount of heat transfer from outside wall to the inside wall. In the double glazed window the material used is basically the low emissivity material so thermal condition can be overcome in some aspect. No heat can transfer from inside wall to outside wall. It is the straight forward approach by which we can save more energy and heat loss could be minimized. There is an advanced version of double glazed window as well that is known as triple glazed window.

In terms of lighting, approximately 90% of the power consumed by an incandescent light bulb is emitted as heat, rather than as visible light. Instead of incandescent light bulbs, Light - Emitting Diodes (LED) or Compact Fluorescent Light bulbs (CFL) will be replaced. CFL bulbs consume 25% of the electricity incandescent bulbs consume in order to provide the same level of illumination, and their approximate lifespan is 6 times of that of incandescent light bulbs. CFL bulbs are significantly more expensive than incandescent light bulbs, with an approximate price ratio 7:1.

A major portion of residential electricity consumption belongs to major household appliances like fan, television, refrigerators are responsible for 60% of electricity. To encourage the energy efficiency, labelling systems have been introduced. The most common labelling program is the “Energy star” program, which was initiated in U.S.A. in 1992, creating a labelling system to promote the use of energy efficient devices. Fans are one of the electrical appliances which have come almost an indispensable in Indian homes and offices. In many middle class Indian homes at least one ceiling fan keep running as an average 20hours a day for almost 300 days in a year. A ceiling fan with its speed regulator used to consume about 80 to 100 best energy efficient ceiling fans as manufactured by reputed ceiling fan manufacturers now come with a wattage in the range 45 to 60 watts. Now fans come with Bureau of Energy Efficiency (BEE) star ratings. A five star rated 1200mm sweep ceiling fan of a reputed make consumes about 45 watts combined with its electronic speed regulator and costs about Rs.2000 per set, which is the more energy efficiency fans in India. If consumers only bought new energy star labelled fans, televisions and refrigerators greenhouse emission would decrease by 4.5billion pounds per year, equivalent to reducing emissions levels by 370,000 cars [7]. There are many other possible methods that can be applied to improve energy efficiency in households. The above mentioned were particularly chosen as they are available to the common user, regardless their socioeconomic status or the location of the building the user resides in.

3 Problem Formulation

Tamilnadu is in the tropical climate region with little variation in summer and winter temperature. Thus for an estimated basal area of 100m^2, total roof area can be calculated approximately by 80m^2. As we know that solar plates have weight, so installing that on the roof strength of floor matters and also the durability of roof. So for this reason we cannot install or cover whole roof are with solar plates. In the building 6 rooms are available. In that 10 incandescent bulb is used which is sufficient for the lighting of the building.

Table 1: Layout details of the house

House specification	Quantity
Total base area,m^2	100
Total roof area available for solar panel installation,m^2	50
Total window area,m^2	16
Total number of rooms	6
Lighting requirements	10x100w incandescent bulb

Table 2: Details of solar photovoltaic solar panels

Capacity(W)	Area(m^2)	Cost(Rs)	Efficiency(W/Rs)
50	0.42	3100	0.278
60	0.50	3610	0.282
100	0.80	5700	0.345
120	0.90	6800	0.365
140	1.02	7000	0.340
180	1.32	8000	0.386

The costs, areas and of solar panels were obtained from different distributors websites [14] price values of different products with same capacities (in watts) were gathered and their averages were taken to calculate the final price. Prices of double glazed window unit were also obtained from local manufacturer’s websites [19,20]. In double glazing technology the air layer thickness as 12mm and the glass thickness on either side as 4mm. Then the average cost of 1m^2 of double glazed window was found to be approximately Rs.1600. The energy saving calculations was performed by taking into account both conductive and convective heat transfer mechanism while neglecting any possible contribution of radiation. The calculations are given below [2].

$$Q=\frac{\Delta T}{1/A\left(\frac{1}{h}+\frac{dg}{kg}+\frac{da}{ka}+\frac{dg}{kg}+\frac{1}{h}\right)}$$

Q – heat transfer rate through the window unit, w

ΔT- average temperature difference between inside and outside during winter °C

A-surface area of double glazed window to be installed m^2

H- heat transfer coefficient of air w/m^2 °C

d_g- thickness of glass layer, m

k_g- thermal conductivity of glass layer, w/m^2 °C

d_a- thickness of air layer, m

k_a- thermal conductivity of air layer w/m^2 °C

Here Q defines the heat flux through a double glazed window unit. The average temperature of Tamilnadu was 35°C in peak summer [23]. If the ideal living temperature inside a house is taken as approximately22°C (73°F) then ΔT value can be found as 13°C. The following table 3 summarizes the calculation parameters, energy saving in terms of heat flux rate and cost of double glazed window purchase and installation.

Table 3: Details of double glazed window

ΔT(°C)	h W/(m^2°C)	d_g(m)	k_gW/(m^2°C)	d_a(m)	k_aW/(m^2°C)	Q_{reg}(W/m^2)	Q_{dg}(W/m^2)	Q_{save}(W/m^2)	C_{dg}(Rs/m^2)
13	45	0.004	0.96	0.012	0.026	279.3	29.4	249.9	1600

The prices and power consumptions of CFL light bulbs were obtained from a distributor company's website [17] while choosing the CFL bulbs that would replace the incandescent bulbs, the criterion was to achieve the same level of lighting as in case of a 100W incandescent bulb. The average power consumption of a CFL bulb that would provide the same level of lighting as in the case of a 100-W incandescent light bulb (≈1600 lumens) was found as 26.5W. Hence the energy gain by replacing incandescent bulbs with CFL bulbs was found 76.5W per bulb. The average cost of a single CFL bulb was Rs.375.

The prices and power consumptions of home appliances (fan, television, and refrigerators) were obtained from different manufacturer's website [22].

- All the fans are optimum performance even at low voltages
- All the television were 22 inches
- All the refrigerators were selected approximate storage space 250 *l*.

Refrigerators operate almost 365 days a year, 24h a day. Fans are operated almost 20hrs a day, televisions are operated 8 hours a day. Refrigerators consume more energy when compared to fans and televisions on an annual basis. The manufacturers express the energy consumption of their refrigerators as KWh per year, whereas for fans and televisions the energy consumption values are given as KWh per run. Instead of using the actual power requirements of all these three appliance types, we only decided to use the actual power requirement of a refrigerator. For fans and televisions, we decided to define a new term called the adjusted power requirement. The calculation details of adjusted requirements of fans and televisions as follows.

$$P_r=\frac{1000E_r}{365x24}$$

$$P^a{}_f=\frac{1000xE_f xNh_f}{365x24}$$

$$P^a{}_{tv}=\frac{1000xE_{tv}xNh_{tv}}{365x24}$$

where

E_r, actual energy consumption of a refrigerator per year, KWh

$P^a{}_f$, adjusted power requirement of a fan, W

E_f, actual energy consumption of a fan per run, KWh

$N^h{}_f$, number of hours a fan is operated in a year

$P^a{}_{tv}$, adjusted power requirement of a television, W

E_{tv}, actual energy consumption of a television per run, KWh

$N^h{}_{tv}$, number of hours a television is operated in a year

E_r, E_f and E_{tv} values were obtained from the manufacturer's websites. During the calculation of adjusted power requirements, both $N^h{}_f$ and $N^h{}_{tv}$ values are taken as 20 and 8 respectively. The constants 365, 24 and 1000 denote the number of days in a year, number of hours in a day and conversion factor from KW to W, respectively.

While calculating the price values the average of the prices of similar products was taken. The same approach was also followed while calculating the power consumptions, the maximum acceptable energy consumption (KWh) values of each appliance with different energy labels were obtained from available literature. Then the average of the maximum acceptable energy consumption values of C and B-energy class appliances was taken. The average power requirements of a C-energy class refrigerator, fan and televisions were found as 98W, 75W and 60W respectively. Table 4 below summarizes the average prices and average power requirements of A-energy class appliances as well as the energy savings when compared to C-Energy class.

Table 4:

Power requirements, energy savings and cost of A-energy class home appliances

Appliances	Power requirement(W)	Energy savings(W)	Cost (Rs)
Refrigerator	120	60	18,999
Fan	53	22	1695
Television	35	25	9548

4.Mathematical Modelling

The following represents the linear programming model for above said costs and savings data and considering the physicals constraints. x, y_i, z, r, f, tv are decision variables of the model.

$$Max\ Z=(R_x{*}x)+\sum_{i=1}^{n}\left(R_{y_j} * y_j\right)+(R_z{*}z)+(R_r{*}r)+(R_f{*}f)+(R_{tv}{*}tv)$$

$$(C_x{*}x)+\sum_{i=1}^{n}\left(C_{y_j} * y_j\right)+(C_z{*}z)+(C_r{*}r)+(C_f{*}f)+(C_{tv}{*}tv)\leq w$$

$$x\leq l$$

$$\sum_{i=1}^{n}\left(y_j * a_j\right)\leq s$$

$$N\leq b$$

where

x, double glazed window area

y_i, the number of ith type with photovoltaic solar panel to be purchased

N, the number of incandescent light bulbs to be replaced with CFL bulbs

$$r=\begin{cases}1\ if\ C-class\ refrigerator\ is\ replaced\ with\ A-class\ refrigerator\\ 0\ otherwise\end{cases}$$

$$f=\begin{cases}1\ if\ C-class\ fan\ is\ replaced\ with\ A-class\ fan\\ 0\ otherwise\end{cases}$$

$$tv=\begin{cases}1\ if\ C-class\ television\ is\ replaced\ with\ A-class\ television\\ 0\ otherwise\end{cases}$$

where

R_x, energy savings rate by installing $1m^2$ of double glazed window, W

R_{yj}, electricity production rate of solar panel type j, W

R_z, energy consumption rate difference between incandescent and CFL light bulbs, W

R_r, adjusted energy consumption rate difference between C-energy class and A-energy class refrigerators, W

R_f, adjusted energy consumption rate difference between C-energy class and A-energy class fans, W

R_{tv}, adjusted energy consumption rate difference between C-energy class and A-energy class televisions, W

C_x, average purchase and installation cost of $1m^2$ double glazed window

C_{yj}, average purchase and installation cost of solar panel type j

C_z, average cost of one CFL light bulb

C_r, average cost of one A-energy class refrigerator

C_f, average cost of one A-energy class fan

C_{tv}, average cost of one A-energy class television

l, total window area,m^2

a_j, area of solar panel type j

s, total available roof area,m^2

b, maximum number of CFL light bulbs that can be purchased for the house

Table 5: Optimization for low range budget

Budget (Rs)	Double-glazed window (m^2)	Solar panel installation(#)						CFL bulbs (#)	Appliances			Total energy savings (W)
		Type 1	Type 2	Type 3	Type 4	Type 5	Type 6		RFG [1]	FAN [2]	TV [3]	
10,000	3	0	0	0	0	0	0	10	0	0	0	1741.2
20,000	10	0	0	0	0	0	0	10	0	0	0	3303.0
30,000	16	0	0	0	0	0	0	10	0	0	0	4864.9
40,000	22	0	0	0	0	0	0	10	0	0	0	6426.7
50,000	28	0	0	0	0	0	0	10	0	0	0	7988.6
60,000	32	0	0	0	0	0	0	10	0	0	0	8875.4
70,000	32	0	0	0	0	0	1	10	0	0	0	9100.4
80,000	32	0	0	0	0	0	3	10	0	0	0	9325.4
90,000	32	0	0	0	0	0	4	10	0	0	0	9550.4
1,00,000	32	0	0	0	0	0	5	10	0	0	0	9775.4

[1] Refrigerator
[2] Fan
[3] Television

Table 6: Optimization for medium range budget

Budget (Rs)	Double glazed window (m²)	Solar panel installation(#)						CFL bulbs (#)	Appliances			Total energy savings (W)
		Type 1	Type 2	Type 3	Type 4	Type 5	Type 6		RFG[1]	FAN[2]	TV[3]	
1,50,000	32	0	0	0	0	11	0	10	0	0	0	10900.4
1,80,000	32	0	0	0	0	15	0	10	0	0	0	11575.4
2,10,000	32	0	0	0	0	19	0	10	0	0	0	12250.4
2,40,000	32	0	0	0	0	23	0	10	0	0	0	12925.4
2,70,000	32	0	0	0	0	26	0	10	0	0	0	13600.4
3,00,000	32	0	0	0	0	30	0	10	0	0	0	14275.4

[1] Refrigerator
[2] Fan
[3] Television

Table 7: Optimization for high range budgets

Budget (Rs)	Double glazed window (m²)	Solar panel installation(#)						CFL bulbs (#)	Appliances			Total energy savings (W)
		Type 1	Type 2	Type 3	Type 4	Type 5	Type 6		RFG[1]	FAN[2]	TV[3]	
5,00,000	32	0	0	0	0	53	0	10	1	1	0	18389.5
5,50,000	32	0	0	0	0	49	14	10	1	1	1	18459.3
6,00,000	32	0	0	0	0	68	0	10	1	1	1	18476.6
6,50,000	32	0	0	0	0	68	0	10	1	1	1	18476.6
7,00,000	32	0	0	0	0	68	0	10	1	1	1	18476.6

[1] Refrigerator
[2] Fan
[3] Television

5 Results and discussion

During the allocation analysis, three budget regions were defined:

(i) Low budget: which is from 10,000 to 1,00,000
(ii) Medium budget: which is from 1,50,000 to 3,00,000
(iii) High budget: which is from 5,00,000 to 7,00,000

The increment between budget values for low budget range was selected as Rs.10,000 whereas the increment for medium range budget was selected as Rs.30,000 and the increment for high budget range was selected as Rs.1,00,000.

When the data in Table **5** is considered, we see that on the low budget the best solution for energy efficiency is replacing incandescent bulb to CFL bulb and installing double glazed window. In this process when we replace all the bulbs of building with the CFL bulbs and all windows are replaced by double glazed window then we need to do some extra and effective method. After that our next step is to install solar panel. For this we have taken six types of solar panel with different efficiency. Each solar panel has its own capacity and power consumption. Among 6 types of solar panel type5 solar panel is suitable for this problem. Performance of type5 solar panel is very good in the unit of capacity, price and power. In this case we have seen that replacing the appliance is not the good option for energy savings. But installation of solar panel comes as a feasible and good option in spite of more cost of solar panel. When the solar panel installed in the multiple units it gives a tremendous result. Renewing the appliance does not seem to be an economical choice. After installing double glazed window we can install solar plate. Solar panel shows highest energy savings. But this is applicable in the case only when we have high budgets. In that case replacement of appliances shows a good option for the energy savings. As we have seen in the result that we are getting highest energy saving in the budget of Rs 6,00,000. In that case maximum amount of energy saving is 18476.6 watts. This amount of energy savings is taken by appropriate readings of all the data like number of bulbs and installation of solar panel. Under the budget range of Rs.5,00,000 to Rs.7,00,000 maximum amount of energy savings obtained.

The parameters that gives the maximum energy saving is given below:

- 32 m^2 area of double glazed window installed
- To purchase 10 CFL light bulbs
- To install 68 "type 5" solar panels
- To replace refrigerators, fans and televisions

To improve energy efficiency of a typical household in Tamilnadu, total amount of Rs.6,00,000 can be spent. Since this study aims at developing a consumer based methodology to maximize energy savings as a function of budget, the payback period of the investment and the profitability rather than the energy savings would be more accurate indicators of feasibility. So the payback period is calculated by some conversion factors, such as power values are converting in to KWh supposing that gain in the energy is throughout the year. Average cost of electricity in India (neglecting slight variation) was obtained as Rs.2.60 per KWh. Time value of money was neglected. The formula for payback period is

$$PP = \frac{1000xB}{365x24xESx2.60}$$

where PP is payback period(in years), 1000 is conversion factor from KW to W, B is budget(Rs), 365, 24 denote the number of days in a year and hours in a day, respectively. ES is the energy savings (W) and 2.60 is the average cost of electricity in Tamilnadu (Rs/KWh). In the result, we can recover our budget or investment in very less time.

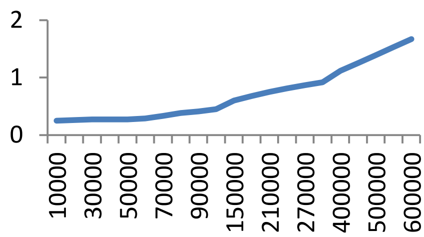

Fig1: Payback periods of energy saving investment as a function of budget

profitability of the problem was calculated by using the below formula:

$$PR = \frac{nx(ESx365x24x2.60)}{1000} - B$$

Table 8: Profitability results over 5 years as a function of budget

Budget (Rs)	1st year profit (Rs)	2nd year profit (Rs)	3rd year profit (Rs)	4th year profit (Rs)	5th year profit (Rs)
10,000	29,657.6	69,315.1	1,08,972.7	1,48,630.2	1,88,287.8
20,000	55229.1	1,30,458.2	2,05,687.3	2,80,916.5	3,56,145.6
30,000	80802.9	1,91,605.9	3,02,408.8	4,13,211.8	5,24,014.8
40,000	1,06,374.5	2,52,749.0	3,99,123.5	5,45,498.1	6,91,872.6
50,000	1,31,948.3	3,13,896.7	4,95,845.0	6,77,793.4	8,59,741.8
60,000	1,42,146.1	3,44,292.2	5,46,438.3	7,48,584.4	9,50,730.6
70,000	1,37,270.7	3,44,541.4	5,51,812.1	7,59,082.8	9,66,353.6
80,000	1,32,395.3	3,44,790.6	5,57,185.9	7,69,581.2	9,81,976.6
90,000	1,25,719.9	3,45,039.8	5,62,559.7	7,80,079.6	9,97,599.6
1,00,000	1,22644.5	3,45,289.0	5,67,933.5	7,90,578.0	10,13,222.6
1,50,000	98,267.5	3,46,535.0	5,94,802.5	8,43,070.1	10,91,337.5
1,80,000	83,641.3	3,47,282.6	6,10,923.9	8,74,565.2	11,38,206.6
2,10,000	69,015.1	3,48,030.2	6,27,045.3	9,06,060.4	11,85,075.6
2,40,000	54,388.9	3,48,777.8	6,43,166.7	9,37,555.6	12,31,944.6
2,70,000	39,762.7	3,49,525.4	6,59,288.1	9,69,050.8	12,78,813.6
3,00,000	25,136.5	3,50,273.0	6,75,409.5	10,00,546.0	13,25,682.6
5,00,000	-81,160.9	3,37,678.5	7,56,517.7	11,75,357.0	15,94,196.2
5,50,000	-1,29,570.9	2,90,858.0	7,11,287.1	11,31,716.0	15,52,145.1
6,00,000	-1,79,176.9	2,41,646.0	6,62,469.1	10,83,292.1	15,04,115.2
6,50,000	-2,29,176.9	2,41,646.0	6,62,469.1	10,83,292.1	15,04,115.2
7,00,000	-2,79,176.9	2,41,646.0	6,62,469.1	10,83,292.1	15,04,115.2

Table 8 shows the profitability analysis. The values in above table shows that a maximum profit value for every budget. For low budget Rs.60,000 seems to be the optimum decision, returning a profit of Rs.1, 42,146.1 at the end of first year and Rs.3,44,292.2 at the end of second year. For high range budgets Rs.5,00,000 seems to be optimum decision ,returning profit of Rs.11,75,357.0, Rs.15,94,196.2 at the end of fourth and fifth years respectively.

6 Conclusion

In this paper, linear programming method was used to maximize energy savings subject to budget for a hypothetical house in Tamilnadu, India. To decrease the building's energy consumption were installing solar panels on the roof, replacing incandescent light bulbs with compact fluorescent light bulbs, installing double glazed windows and replacing C-Energy class appliances(refrigerators, fans and television) with A-Energy class appliances. Lingo 14.0 software was used to solve the linear optimization. The energy savings were calculated as a function of total allowable budget, and budgets ranging between Rs. 10,000 and Rs.7,00,000 were used as inputs for the model. The maximum amount of energy savings was found to be 18476.6 W, at a budget of Rs.6, 00,000.

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