ECONOMICS BRIDGE BETWEEN THEORY AND PRACTICE OF SUSTAINABLE BUILT ENVIRONMENT: A CASE FOR MARGINAL BENEFIT AND MARGINAL COST

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ABSTRACT: Common economic gauges that validate Sustainable Built Environment (SBE) in households may cause for such projects to be shelved especially when the result of commercial feasibility study does not favour the stakeholders. It is a fact that the capital cost of Energy Efficient (EE) equipment and Renewable Energy (RE) system are more expensive than the conventional methods. However, SBE is now necessary and the gap between theory and practical of SBE in relation to economics aspect must be narrowed. The economics of SBE must not only assert the environmental implication but also make tangible its benefit to the household for championing the cause. In Economics, Marginal Cost (MC) and Marginal Benefits (MB) measure additional benefits of every additional costs of investment at a specific level of production and consumption; and Economists suggests that effective gain and loss must be compared to the status quo, i.e., Relative Position (RP). These Economics theories of MC, MB and RP are adapted to measure the progression of SBE with regards to lighting requirements in a living/dining area simulated to represent two types of houses: with and without Passive Architecture (PA) design strategies. Both are applied with conventional incandescent light bulbs and EE light fittings as well as RE in lieu of the mains electricity supply. The comparative approach shows the value of MB and MC at every stage of the SBE progression and this enables the household to make informed decision at a margin. The result suggests that the value of MB is more than MC when both cases use EE light fittings, i.e., approximately RM2 gain for every RM1 cost. It is also found that RE benefits the household more in PA case. This approach makes economic sense in so far encouraging household to opt for SBE.

Keywords: Economics, Marginal Benefits, Marginal Costs and Energy

1. INTRODUCTION

1.1 Economic Viability of Sustainable Built Environment (SBE)

Sustainable Built Environment (SBE) is when a building has no negative impact to the environment and become self-sustenance (Williamson, 2003). From energy perspective, SBE is when building uses less of commercially supplied energy and become independent from the mains electricity supply. Common SBE approach is the application of Energy Efficient (EE) equipment or Renewable Energy (RE) system. However, Pusat Tenaga Malaysia (PTM) commented that SBE in local application is far-fetched due to the high capital cost of EE and RE compared to the alternative methods (PTM, 2007). The same applies in overseas. (Lesourd, 2001 and Smith, 2005). This study believes that the typical economics scales measuring SBE such as Life Cycle Assessment (LCA), Cost Benefit Analysis (CBA), Payback Time (PBT) and Return on Investment (ROI) are the actual hindrance to SBE implementation.

LCA appraises the environmental effect and energy consumption of a product at each stage of its life. CBA evaluates the net economic impact of a project in relation to many other factors such as social, political, geographical, etc. In other words, LCA and CBA deal with macroeconomics and this is a fundamental problem in so far SBE in household is concerned. It is unlikely for a household to expend its limited resources for a cause at the macro level when there is a concern about achieving a certain level of economics benefit in the household itself (PTM, 2007). Although PBT and ROI look at SBE from the household's viewpoint, unfortunately both methods are too simplistic in their approaches (Perev, 2004).

Housing forms the largest portion of built environment and mass adoption of SBE by households would have a significant effect in slowing down global warming (Szokolay, 2006). Hence, it is a big loss when households dismiss SBE due to the weak economics presentation. The economics of SBE need to be re-presented from households' perspective - i.e., what is their tangible gain for expending their limited resources.

1.2 Sustainable Built Environment in Household

SBE should be approached as a continual design improvement in a household. It can start with incorporating Passive Architecture (PA) design strategies that asserts Energy Conservation (EC), installing EE equipment and applying RE such as Building Integrated Photovoltaic (BIPV) system. All of these steps will lead to household consuming low Operational Energy (OE) and becomes less dependent on commercially supplied energy and effect for some economics gain in Energy Savings Benefit (Fig. 1).

This paper advocates that if making SBE is advancement from EC, EE and RE, then the cost and benefit of such action is also a progression to the status quo. If the comparative ratio of benefits and costs in SBE (from one stage to another) is positive, the investment should be worth the while.

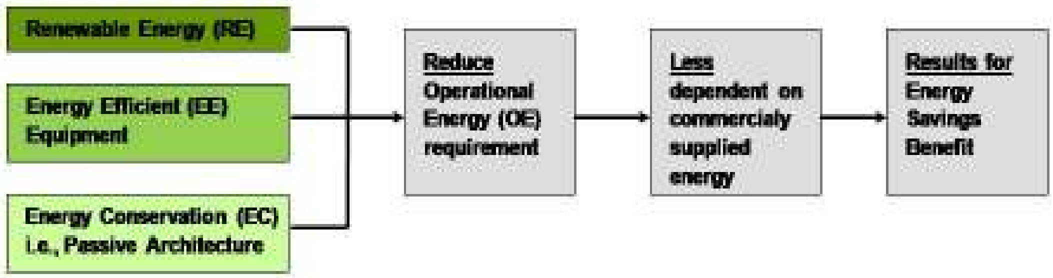


Figure 1. RE, EE and CE Reduces Operational Energy and Lead to Energy Savings Benefit

2 MARGINAL BENEFIT (MB) AND MARGINAL COST (MC)

In Economics, the "right amount" of anything is the "optimal" or "efficient" amount i.e., Marginal Benefit (MB) equals Marginal Cost (MC); and the word "marginal" is synonym for "additional" (Arnold, 2005). The term MC and MB are commonly used to describe the efficiency of production line, i.e., how much more resources to apply for additional gain in productivity. Economists also suggest that when making a decision, people actually think in terms of cost and benefit at a margin because most decisions deal with making additional change to what they already have, not total costs of benefits (Arnold, 2005a). Relating this to LCA, CBA, ROI and PBT, these methods present the total costs and benefits of doing SBE; hence the resultant arithmetic is a put off to household.

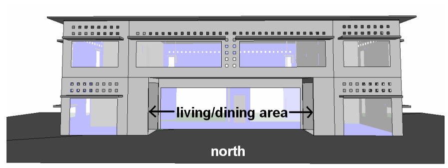
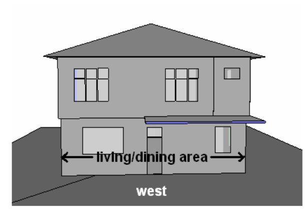
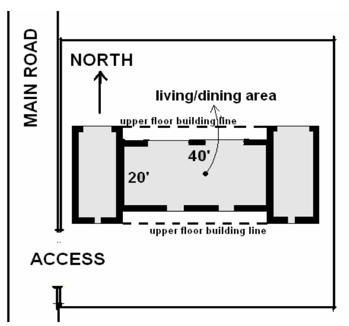
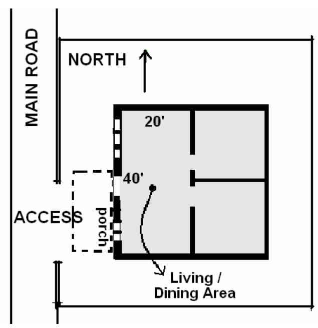
Another Economics theory, 'Relative Position' (RP) suggests that households' decision for consumption and savings are influenced by their comparative assessment of their accomplishments and how these stack up against those of others (Daly, 2007). This paper intends to show the potential of measuring SBE in household using the Economics theory of MB, MC and RP. This comparative approach enables household to see the marginal effect at each stage of SBE development.

3 METHODOLOGY

3.1 Part 1: Daylight in living/dining areas of non PA and PA cases

The study has identified two houses that represent a PA Case and a non PA Case. The former is designed with climate factors while the latter appears to be lack of consideration for local climate. The living/dining areas of these two cases are replicated to ensure both have the same built parameters (Table 1). The amount of daylight they received is ascertained using recognized software.

Table 1. The Comparison of Living/dining Area in PA and Non PA Cases

	PA Case	Non PA Case
Precedent		
Simulated elevation of the living/dining are		
Simulated floor plan of the living/dining are		
Design Strategies for the living/dining area	■ North orientation; ■ Slender form elongated east-west; ■ Large openings on the north facade; and ■ Recessed floor plan on the north and south sides.	■ West orientation; ■ Square form with concentric rooms arrangement; ■ Medium-sized openings on all facades with undersized shading devices; and ■ Porch at the front, for vehicle parking.
Cause	Building elements (orientation, form, openings and sun shading devices) are designed with climate factors in mind	Building elements are merely construction elements and disregard climate factors
Effect	=> long period of daylight => need less artificial lighting => low operational energy => need less commercially supplied energy => claims Energy Savings Benefit	=> short period of daylight => rely on artificial lighting => high operational energy => need more commercially supplied energy

The daylight readings of these cases are compared to the recommended visual comfort by the Malaysian Standard MS 1525:2007 for reading and writing, i.e., 300 lux (SIRIM, 2007) - considering the living/dining area has high practical use. It is assumed that when the space receives daylight illuminance of 300 lux, it would not require artificial lighting and that personal adaptation would not involve any operational energy. On the other hand, when the space receives daylight illuminance below 300 lux, it is taken that the space needs artificial lighting; hence, need to consume electricity.

3.2 Part 2: Power Consumption at 8 Stages of SBE

The simulation result in Part 1 is used as a basis to ascertain the power consumed by artificial lighting in living/dining area of both PA and non PA cases at every stage of the SBE progression (Table 2).

Table 2. Eight Stages of SBE Progression in the Study

Stage	Case	Type of Lighting	Type of Power
1	Non PA	Incandescent	Mains Supply
2	Non PA	Incandescent	BIPV
3	Non PA	CFL	Main Supply
4	Non PA	CFL	BIPV
5	PA	Incandescent	Mains Supply
6	PA	Incandescent	BIPV
7	PA	CFL	Main Supply
8	PA	CFL	BIPV

The initial stage starts with the living/dining area in non PA case using incandescent light bulb and powered by mains electricity supply. At the 2nd stage, the mains power supply is replaced with RE, i.e., BIPV. At the following 3rd stage the incandescent light bulb is replaced with EE light fitting, i.e., Compact Fluorescent Light (CFL). The last stage for the non PA case is the 4th stage where the living/dining area is equipped with both CFL and use BIPV. The change in house design incorporating climate factors begin at the 5th stage, i.e., PA case but it uses incandescent light bulb powered by mains electricity supply. This study accepts the notion that there is no additional construction cost in creating a PA case, only critical design thoughts by the designers

(Olgyay, 1963 and Brown 2001). Stages 2, 3 and 4 in non PA case are repeated in stages 6, 7 and 8 of the PA case.

3.3 Part 3: Calculation of MB and MC

The result in Part 2 forms the basis for MC and MB. MB is basically all the benefits attributed by the design of the case, while MC consists of all the costs that need to be expended by the household at a particular stage of the SBE progression (Table 3).

Table 3. Breakdown of Marginal Benefits and Marginal Costs

	Marginal Benefits (MB)		Marginal Costs (MB)
MB_1	savings from consuming less electricity from TNB as a result of using EE light bulbs, i.e., CFL and PA case	MC_1	cost of mains electricity supply from TNB (for either incandescent lights or CFL) due to the need for artificial lighting
MB_2	savings for spending less on light bulb as a result of longer service life of EE light bulb such as CFL	MC_2	cost of the type of light fittings (for either incandescent lights or CFL) used in the living/dining area
MB_3	savings from not consuming mains electricity supply from TNB due to using full-fledged RE, i.e., BIPV	MC_3	capital cost of RE, i.e. BIPV meeting the exact requirement of the living/dining area in each case

4 FINDINGS

4.1 Part 1: Daylight

The daylight opportunity measured in the simulation is based on standard overcast sky as defined by the CIE (Commission Internationale d'Eclairage). The duration was approximately 12 hours from 7:00 a.m. to 7:00 p.m. every day and the 15th day of every month represents a typical day of the month. The daylight analysis was carried out onto an imaginary working plane of 0.85 metre-high in the living/dining area to reflect the operational level.

When one-third of the living/dining area reads 300 lux of daylight, it is assumed that the occupant would still need artificial lightings in order to compensate for the insufficient illuminaire at the other part of the space; and in this case it is generalized as having inadequate daylight (Fig.2 and Fig.3).

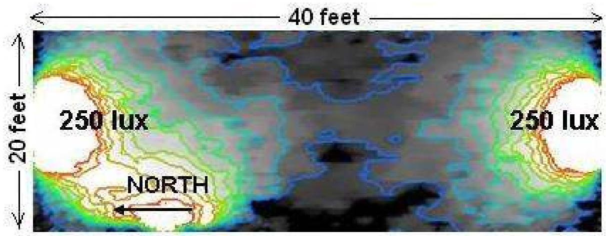


Figure 2: Inadequate daylight in non PA Case - floor plan showing illuminance reading averaged at 250 lux in the living/dining area at 9:00 a.m. on 15th June.

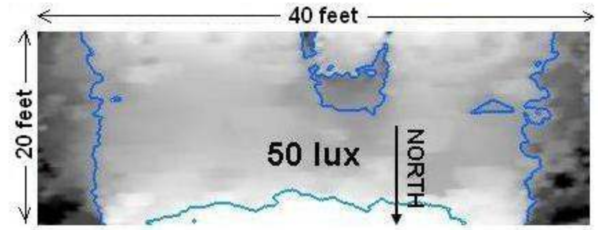


Figure 3: Inadequate daylight in PA Case - floor plan showing illuminance reading averaged at 50 lux in the living/dining area at 7:00 p.m. on 15th June .

On the other hand, when two-third of the space receives daylight illuminance reading exceeding 300 lux, the living/dining area would be considered as well lighted and does not need artificial lighting (Fig.4 and Fig. 5).

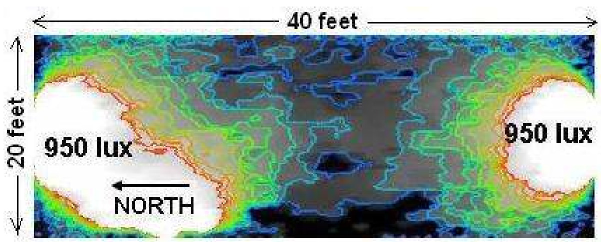


Figure 4: Adequate daylight in non PA Case - room plan showing illuminance reading averaged at 950 lux in the living/dining area at 3:00 p.m. on 15th June.

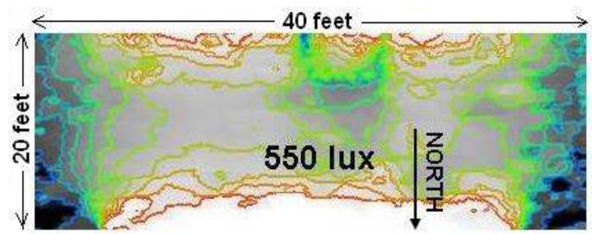


Figure 5: Adequate daylight in PA Case - room plan showing illuminance reading averaged at 550 lux in the living/dining area at 3:00 p.m. on 15th June.

When simulated for every 15th day of the month, non-PA Case had insufficient daylight and had to rely on artificial lighting for 5 to 7 hours per day during daytime and additional 5 hours at night time. Meanwhile, PA Case had inadequate daylight for a maximum of 3 hours per day as it had managed to receive adequate daylight during most part of the daytime. Similarly, PA case needs 5 hours of artificial lighting at night time; hence relying on artificial lighting for total of 7 to 8 hours per day (Table 4).

Table 4: Daily Requirement of Artificial Lighting in Non PA and PA Cases

15th day of the month	**Jan**	**Feb**	**Mac**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Time required artificial lighting in non PA Case (hours/day)	10	10	10	10	11	12	12	11	10	10	11	10
Time required artificial lighting in PA Case (hours/day)	8	8	8	8	7	7	7	7	7	7	8	8

4.2 Part 2: Artificial Lighting Expenditure

Mahlia (2005) suggests that 18-watt EE light bulb can replace incandescent light bulb of 100-watt for equivalent output. The service life of EE light bulb is 5000 hours but it costs 8 to 17 times more than price of incandescent light bulbs that last about 750 hours. Mains electricity supply by Tenaga Nasional Berhad (TNB) for domestic tariff is 21.80 sen/kWh for the first 200kW but increases to 28.90 sen/kWh for the next 800 kWh (TNB, 2008). Based on TNB record, it is assumed that the tariff hike is 12% at every 10 years.

Meanwhile, the cost of BIPV is RM26,000 per 1 kWp (PTM, 2008). The requirement of BIPV can be determined from the annual power consumption using artificial lighting of each case whereby 1100 kWh is equivalent to 1kWp of BIPV for 30 years service life; hence, the period of assessment in this study.

From the above data, the cost of light fittings for incandescent light bulbs and CFL as well as the TNB electricity bill and cost of BIPV for living/dining area in non PA case can be ascertained (Table 5). Similarly, the same can be deduced for living/dining area of PA case (Table 6).

Table 5: Costs of Light Bulbs, Electricity and BIPV for Living/Dining Area of Non PA Case

NON PA CASE LIVING/DINING AREA	Incandescent Bulbs		EE CFL	
Wattage per 6 units lights	0.6	kW	0.108	kW
Service life	750	hours	5000	hours
Cost per unit (Mahlia, 2005)	1.4	MYR	18.50	MYR
Cost per 6 units	8.4	MYR	111	MYR
Hours of artificial lighting per year	3,864	hours	3,864	hours
Light replacements	5.15	times	0.77	times
Cost of 6 light bulbs per year	43.28	MYR	85.78	MYR
Cost of 6 light bulbs per 30 years	1,298.30	MYR	2,573.42	MYR
TNB Bill (1st 200 kw = 21.8 sen, next 800 kW = 24.4 sen)				
TNB Bill per year	506.67	MYR	90.97	MYR
TNB Bill per 30 year @ 12% tariff hike	17,134.67	MYR	3,067.24	MYR
BIPV (1 kWp = 1100 kWh annual power consumption @ RM26,000 per kWp)				
Annual power consumption	2,318.40	kWh	417.31	kWh
BIPV required per year	0.07	kWp	0.01	kWp
BIPV required per 30 year	2.11	kWp	0.38	kWp
Cost of BIPV per year	1,826.62	MYR	328.79	MYR
Cost of BIPV per 30 year	54,798.55	MYR	9,863.74	MYR

Table 6: Costs of Light Bulbs, Electricity and BIPV for Living/Dining Area of PA Case

PA CASE LIVING/DINING AREA	Incandescent Bulbs		EE CFL	
Wattage per 6 units lights	0.6	kW	0.108	kW
Service life	750	hours	5000	hours
Cost per unit (Mahlia, 2005)	1.4	MYR	18.5	MYR
Cost per 6 units	8.4	MYR	111	MYR
Hours of artificial lighting per year	2,736	hours	2,736	hours
Light replacements	3.65	times	0.55	times
Cost of 6 light bulbs per year	30.64	MYR	60.74	MYR
Cost of 6 light bulbs per 30 years	919.30	MYR	1,822.18	MYR
TNB Bill (1st 200 kw = 21.8 sen, next 800 kW = 24.4 sen)				
TNB Bill per year	357.87	MYR	64.42	MYR
TNB Bill per 30 year @ 12% tariff hike	12,065.76	MYR	2,171.84	MYR
BIPV (1 kWp = 1100 kWh annual power consumption @ RM26,000 per kWp)				
Annual power consumption	1,641.60	kWh	295.49	kWh
BIPV required per year	0.05	kWp	0.01	kWp
BIPV required per 30 year	1.49	kWp	0.27	kWp
Cost of BIPV per year	1,293.38	MYR	232.81	MYR
Cost of BIPV per 30 year	38,801.45	MYR	6,984.26	MYR

4.3 Part 3: Breakdown of MB and MC

With reference to Tables 3, 5 and 6 the breakdown of MB and MC can be determined (Table 7).

5 DATA ANALYSIS: RATIO MB/MC

The ratio of MB and MC at each stage is being compared against its previous stage as per the theory of RP, using the following formula:

$MB/MC = (MB_1 + MB_2 + MB_3) / (MC_1 + MC_2 + MC_3)$ ……………...(a)

The result shows the gain from every RM1 of investment at every stage of the SBE progression (Table 8). Generally, the gain from RM1 investment in the long term, i.e., 30 years is higher than the short term gain of 1 year. This makes sense because EE and RE inherit high capital cost. At the initial stage, the MB/MC is zero because there is no gain at the status quo. The MB/MC ratio is the highest when the light fittings in the living/dining area is changed from incandescent light bulb to CFL at stages 3 (2.49) and 7 (2.48).

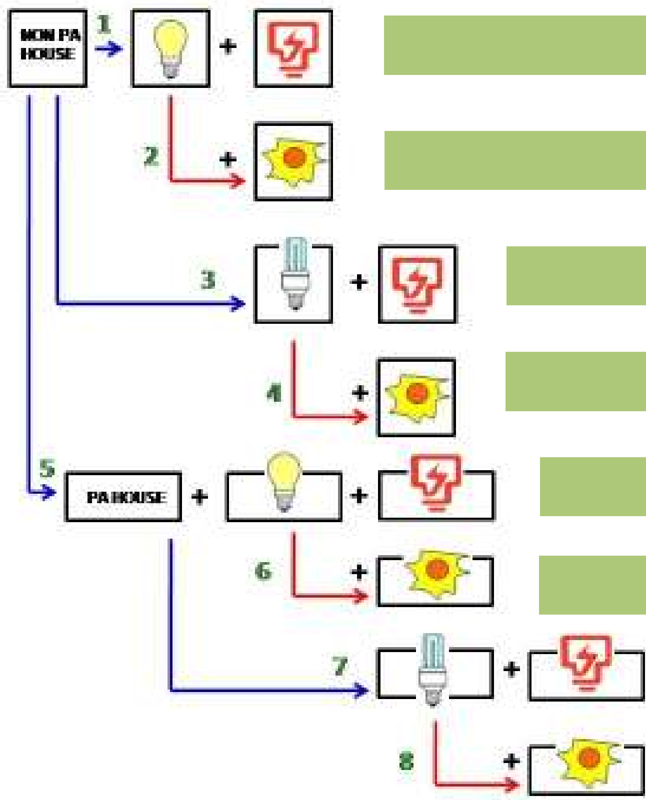
Applying BIPV at stages 2, 4 and 6 only gives RM0.31, RM0.25 and RM0.44 benefits from every RM1, respectively. This is because living/dining area in non PA case needs a lot of artificial lighting. Similarly, using incandescent light bulb even in PA case requires a lot of energy. Meanwhile, using BIPV at stage 8 gives RM1.36 benefit for every RM1 spent because living/dining in PA case requires less artificial lighting; making the actual size of BIPV smaller and cheaper.

Osram (2008) claimed to have developed 20-watt CFL bulb that lasts 15,000 hours but costs 13.5 times more than the equivalent 100-watt incandescent light bulb of 1000 hours service life. Therefore, the study also considers Osram's data that reflects latest technological development of EE lights (Table 8, last column). The MB/MC result is approximately the same as per using Mahlia's data; except for at stage 8 (RM1.94) where the advantage offered by Osram's EE lights, i.e., longer service life, is obvious.

Table 7. Calculation of Marginal Benefits (MB) and Marginal Costs (MC) Breakdown for 30-year Period at Each Stage of the SBE in the Study

	Marginal Benefits (MB)			Marginal Costs (MC)		
Stage	MB_1	MB_2	MB_3	MC_1	MC_2	MC_3
1	0	0	0	17,134.67	1,298.30	0
2	0	0	17,134.67	0	1,298.30	54,798.55
3	17,134.64 - 3,067.24 14,067.43	0	0	3,067.24	2,573.42	0
4	17,134.64 - 3,067.24 14,067.43	0	3,067.24	0	2,573.42	9,863.74
5	17,134.64 - 12,065.76 5,068.91	1,298.30 - 919.30 379.00	0	12,065.76	919.30	0
6	17,134.64 - 12,065.76 5,068.91	1,298.30 - 919.30 379.00	12,065.76	0	919.30	38,801.45
7	12,065.76 - 2,171.84 9,893.92	0	0	2,171.84	1,822.18	0
8	12,065.76 - 2,171.84 9,893.92	0	2,171.84	0	1,822.18	6,984.26

Table 8. Ratio of Marginal Benefits (MB) against Marginal Costs (MC) for 1-year and 30-year Period.



(MB/MC)	1-year (Mahlia)	30-year (Mahlia)	30-year (Osram)
Stage 1	0	0	0
Stage 2	0.27	0.31	0.30
Stage 3	2.35	2.49	2.51
Stage 4	0.22	0.25	1.38
Stage 5	0.42	0.42	0.42
Stage 6	0.39	0.44	0.44
Stage 7	2.34	2.48	2.49
Stage 8	1.33	1.36	1.94

6 CONCLUSION

Fundamentally, MB/MC promotes SBE as a progression from the status quo; and at every stage of its development the household can see the additional benefit and additional cost of making and ignoring SBE. This study, demonstrates that even though the cost of CFL is more expensive than incandescent light bulb, using EE is economically beneficial to household. It is also shown that applying BIPV is more beneficial after applying EE. The potential of this approach can be explored to include cost of using mechanical cooling in a house and other electrical appliances.

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