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A Systematic Method for Cost-effective Carbon Emission Reduction in Buildings

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Abstract: Carbon Emissions Pinch Analysis (CEPA) is a recent advancement in the traditional pinch analysis technique developed in the 70's. It has been applied to determine the minimum amount of zero-carbon energy resources or renewable energy needed to achieve the region's or a country's CO_2 emission reduction target. This study introduces a new holistic framework to cost effectively screen and select the correct electrical energy saving measures for a building to maximize carbon reduction within a desired payback period. The method uses the newly proposed Carbon Management Hierarchy (CMH) to maximize carbon reduction. This is done by plotting the Investment vs. Carbon Reduction (ICR) plot according to the CMH level and based on three heuristics. The final step is to screen the ICR plot using Systematical Hierarchical Approach for Process Screening (SHARPS)' method until the desired payback period by the building owner is achieved. Application of the methodology on a case study gives a reduction 141, 000 kg CO_2-e per annum with an annualized investment cost of MYR42,000 and a payback period of 8 months.

Key words: Carbon reduction, urban building, pinch analysis, energy planning, cost screening

INTRODUCTION

Effects of global warming as a result of greenhouse gas emissions (GHG) have been one of the most highlighted issues of this century. Many initiatives have been done to reduce the GHG especially carbon emissions. Reduction in energy is often related to reduction in carbon emission. The highest energy user in buildings is normally electricity which is used for almost all equipments such as air-conditioning, computers, printers, lightings and many more. For Malaysia, each 1 kWh of energy produces 0.629 kg CO_2 (PTM/DANIDA, 2006).

Most of previous works on electricity reduction that aims to reduce carbon emissions are focused on total site or regional electricity planning (Tan and Foo, 2007; Foo *et al*., 2008; Lee *et al*., 2009). These authors uses Carbon Emissions Pinch Analysis (CEPA) concept to optimize the power generation mix based on demand/emissions targeting including economic constraints, such as the cost of generation and the carbon prices. The CEPA technique was utilized for energy planning in Ireland (Crilly and Zhelev, 2008) and in New Zealand electricity sector (Atkins *et al*., 2010). Furthermore, Foo *et al*. (2008) uses an equivalent numerical approach to solve similar problems.

Other study uses mathematical modeling but also focuses on power generation planning. Mirzaesmaeeli *et al*. (2010) developed a multi period mixed-integer linear programming (MILP) model for energy planning of electric systems. This model determines the optimal mix of energy supply sources and pollutant mitigation measures that meet a specified electricity demand and CO_2 emission targets at minimum cost. Similarly, Hashim *et al*. (2005) developed a MILP but using General Algebraic Modeling System (GAMS). The MILP model was applied to Ontario Power Generation (OPG) to evaluate the best solution for OPG's power plants under three different operating strategies: total cost reduction, CO_2 emissions reduction and an integrated operational mode. Muis *et al*. (2010) has also developed an MILP model to predict the optimal planning of electricity generation schemes for Malaysia in order to meet its CO_2 emission target.

For facility area, Tjan *et al*. (2010) has developed a graphical method that plots 'carbon emission versus economic value' for a chemical process plant. The energy and material based footprints are plotted as the source curve. And the targeted carbon reduction is plotted as demand curve. The authors then proposed several process changes to reduce the carbon emission to

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achieve the carbon reduction target. One of the limitations of this study is that the 'economic value' is calculated only based on the raw material cost. For example, electricity cost is calculated using the following tariff \$0.06 kWh^{-1}.

Based on all these literatures, there are still several research gaps remaining:

- There are no systematic and cost effective electricity and carbon emission reduction tools for buildings
- The electricity reduction measures proposed by previous authors on facilities do not include investment cost of the measures proposed
- Typical energy audit does not consider interaction among several measures when implemented in series
- No systematic ways to perform electrical and carbon reduction systematically and cost effectively based on carbon management hierarchy have been proposed

In this study, a new method is proposed to analyze the most cost-effective electricity reduction measures that can reduce carbon emissions for a building systematically considering all carbon management hierarchy. All this limitations will be addressed using the proposed methodology as described in the next section.

MATERIALS AND METHODS

A holistic cost effective carbon reduction (CECR): This study outlines a new holistic screening tool for Cost-effective Carbon Reduction (CECR), to screen carbon reduction options cost-effectively in building facilities considering only electricity appliances. It adapts part of the study on cost effective minimum water network and SHARPS proposed by Wan Alwi and Manan (2006) and Wan Alwi *et al*. (2008).

Step 1: performing energy audit and calculating carbon emissions from each energy source: In Step 1, energy audit needs to be performed in order to determine the amount of energy used in a facility. In this study, only energy audit related to electricity appliances will be considered. To perform this, energy bills are first collected from a building followed by determining how much energy are used for the appliances. Data are collected through surveys and questionnaires, records etc. The following data are required to carry out an energy/carbon audit:

- Description of buildings (age, area, occupancy numbers)
- A detailed electricity use data usually in kW, from utility bills companies
- Detailed equipment's/appliances in service, with their corresponding capacities and ratings (kW)
- The total number of lighting bulbs, air-conditioning units, refrigerators, computers/printers, motors, lifts, escalators, pumps, etc.
- The number of service hours per week for each equipment and or appliance

Table 1 shows a sample questionnaire for the energy audit data collection. Once all the consumption for each energy using appliances have been determined, the similar appliances are grouped together to determine the total electricity consumption per year for each appliance type. The carbon emission resulting from each of these appliances can then be calculated using Eq. 1. Table 2 shows data extracted from Table 1.

$$\text{Carbon emission (kg } CO_2\text{-e)} = \text{Electricity consumed (kWh)} \times \text{Emission factor} \quad (1)$$

Step 2: Determining possible measures to reduce carbon emissions from each energy source by considering carbon management hierarchy (CMH): Carbon Management Hierarchy (CMH) is a hierarchy proposed in this study to reduce carbon emissions (Fig. 1). The CMH have three levels i.e., conservation, source switching to Renewable Energy (RE) and sequestration arranged in order of increasing priority. Level 1 (Conservation) means the use of energy conservation measures. Energy conservation opportunities (or measures) could result in a more efficient use of or partial or complete replacement of the existing installation. Level 2 (Source switching to RE) means the primary source may be switched for instance from fossil fuel to renewable energy (e.g., biomass, wind, solar), this measure will save cost and reduce CO_2 emissions. Level 3 (Sequestration) means the removal of carbon from the atmosphere and depositing it in "carbon sinks" such as trees, soil, water, etc (e.g., activity 4 in Table 3).

In this step, all possible options to reduce carbon emissions are listed down together with the investment needed and amount of carbon emission it can reduced.

Table 1: Sample data collection sheet

Location	Equipment/Appliance	Qty.	Rating	Operating h/week
Block A	Air conditioner	27	5 HP	32

Table 2: Data extraction

Equip. type	Equip. specs.	Qty.	Electricity demand ($kW\ year^{-1}$)	CO_2 emitted (kg CO_2-e)
Air conditioner	5Hp unit	27	167,581	105,408

Table 3: Sample of options to reduce carbon emission determined based on CMH for hypothetical case study

Process	Level	Strategies	Investment (MYR)	Annual carbon reduction (kg CO_2-e)
Appliance 1	Conservation	M1a		
		Replacing incandescent bulbs with LED bulbs	25,000	56,000
	Conservation	M1b		
		Replacing incandescent bulbs with CFL bulbs	20,000	55,000
	Conservation	M2		
		Switch off vacant room	0	9,000
	Conservation	M3		
		Day lighting	0	7,000
Appliance 2	Conservation	M4		
		Adjust room temperature	0	6,000
	Conservation	M5		
		Replace refrigerants	12,000	35,000
Appliance 3	Source switching	M6		
		Install solar cells	40,000	68,000
Activity 4	Sequestration	M7		
		Plant trees	10,000	29,000

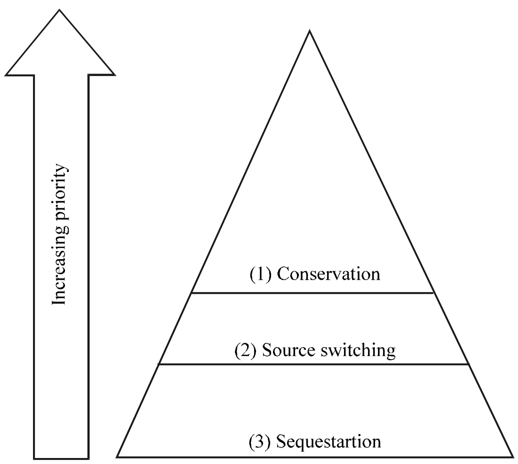

Fig. 1: Carbon management hierarchy

The cost of investment and carbon savings or reduction can be calculated by using Eq. 2 and 3.

In Step 2, all possible carbon reduction or mitigation measures from each energy level in the CMH are determined. The cost of investment and carbon savings or reduction for each measures can be calculated by using Eq. 2 and 3.

$$\text{Investment cost} = \text{Unit cost of Equip.} \times \text{No. of required unit} \quad (2)$$

$$\text{Carbon reduction} = \text{Electricity savings (kWh)} \times \text{Emission factor} \frac{(\text{kg } CO_2)}{\text{kWh}} \quad (3)$$

There may be cases where several technologies or options are available. For example, changing to T8 energy efficient light bulb, changing to LED light bulb and using day lighting are all measures related to lighting appliances. In this case, all the possible options are listed down and will be screened at the later stage. Table 3 shows sample of options to reduce carbon emission determined based on CMH. In this study, options refer to strategies that only one can be implemented at a time (represented with alphabets i.e. a, b, c etc.) example M1a, while measures are strategies that can be implemented together (represented by numbers only) example M3.

Step 3: Plotting investment vs. Carbon reduction (ICR) plot: Step 3 is to plot investment vs. carbon reduction energy (ICR). To plot this, cumulative investment is calculated for the y-axis and cumulative carbon reduction is plotted for the x-axis. The measures are plotted according to the CMH levels and the following heuristics:

Heuristic 1: If there are several measures which can be implemented in parallel, then select the technology with no cost, followed by low to high cost.

For example, both the use of daylight during sunny days and changing light bulb to T8 (an energy efficient bulb) are related to lighting appliances and can be implemented together. However, if we implement the first strategy first, it will affect the carbon reduction calculations of the second strategy (as compared to the base case scenario where no daylight is used). Hence, in this case, the day lighting strategy (no cost) should be plotted first followed by changing to T8 (low cost).

Heuristic 2: If there is more than one possible technology option for the same appliance and only one can be selected, the option which gives the highest carbon reduction is chosen regardless of investment cost.

For example, if light bulbs can be changed to T5, T8 or LED, hence, the highest carbon reduction option which is LED will be chosen.

Heuristic 3: If the options give the same amount of carbon reduction, the lowest investment option is chosen.

For example, if changing light bulbs to CFL and LED have the same carbon reduction but, CFL has lower investment, hence CFL is therefore chosen.

Figure 2 shows a sample of ICR plot. Note that the slope of the graph represents investment per carbon emission savings. The Payback Period (PP) can be calculated by using Eq. 4. Hence, if the initial and final point of the plot is joined together in a straight line, the payback period of the whole mitigation measures can be determined. The unit cost of electricity used in this work is MYR0.288 kWh^{-1}.

$$PP = slope \times \frac{\text{Emission factor}}{\text{Electricity price}} \quad (4)$$

Step 4: screening the carbon emission to obtain cost effective solutions: Step 3 has determined the maximum carbon emission reduction possible for the facility. However, the payback period if all these retrofit are performed might be very high e.g., 30 years which is not practical and not cost effective for building owners to implement. Hence, all the carbon mitigation and reduction measures needs to be screened systematically in order to obtain the highest carbon emission reduction possible within the payback period that a building owner can invest in. To do this, the SHARPS technique by Wan Alwi and Manan (2006) is adopted. SHARPS strategies consist of intensification and substitution method.

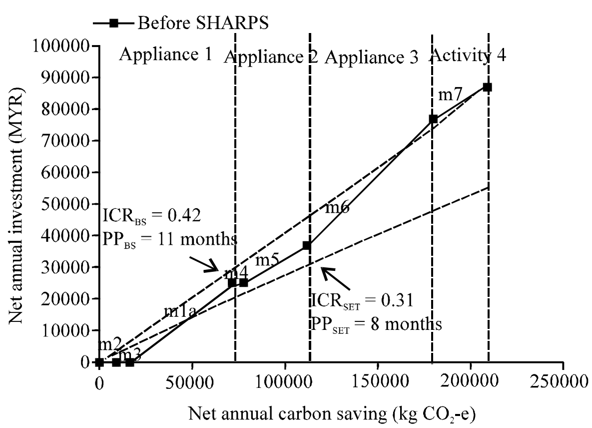

Fig. 2: ICR Plot implementing highest carbon reduction option for levels of CMH

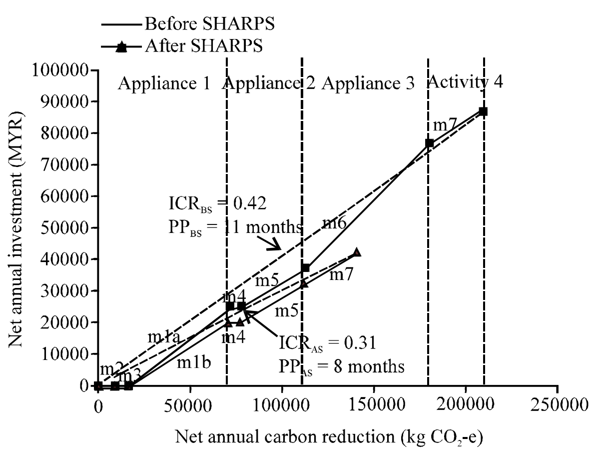

Fig. 3: Final ICR plot that achieves PPset after SHARPS screening

Strategy 1: Intensification-intensification strategy is simply reducing the length of the steepest slope by implementing only part of the measures.

Strategy 2: Substitution-in substitution strategy, the option which is responsible for the steepest gradient is replaced with an option with the next highest CO_2 reduction that gives a lower investment cost.

The slope of each plot signifies the total investment per CO_2 savings (ICR_{BS}), before applying SHARPS strategy. This is then converted to payback period (PP_{BS}) using Eq. 4. Note that the steepest positive gradient (m_{1a}) gives the highest investment (most costly option) per unit of CO_2 savings. If ICR_{BS} is higher than ICR_{set}, then SHARPS strategies (substitution or intensification) are implemented until the desired CR_{set} is achieved. Figure 3 shows that substituting M1a with M1b and eliminating M6 decreases the ICR slope towards the ICR_{set} (8 months).

CONCLUSION

The new holistic framework for Cost-Effective Carbon Reduction (CECR) in buildings is capable of prioritizing and screening the best mitigation option for maximizing CO_2 reduction within a desired payback period. Results from application of the new approach shows that the energy use of the hypothetical case study was significantly reduced by implementing cost effective mitigation measures systematically. This is achieved by selecting the best mitigation measures and options to implement. In the final analysis, results show that an investment of MYR42,000 is needed with a corresponding CO_2 reduction of 141,000 kg CO_2-e and payback period of 8 months.

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