# The Assessment of the Environmental and Economic Performances for Improving Existing Educational Building: A Case Study of Bangkok, Thailand

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***Abstract*—In the present era, buildings are highly contributed to both energy consumption and greenhouse gas emission. As a result, energy conservative measures in building is one of the best tool to tackle these issues which become the global concerns. The purpose of this study was aimed to make the assessment for the environmental and economic performances by the implementation of energy conservative measures for the educational buildings in Thailand. The clean development mechanism (CDM) methodology and net present value (NPV) were used for the study analysis. The results demonstrated that among all of the feasible measures, the top three options for environmental performances improvement were building management, high efficiency of air conditioner replacement and solar cell installation. For the Improvement of economic performance, the automatic system control, saving practices, air conditioner maintenance and lighting efficiency improvement were suggested as the solution tools. The obtained results can be useful for the decision makers to make the strategies planning for building sector in the upcoming future.**

***Index Terms*—Educational building, economic performance, energy conservative measure, environmental management.**

## I. Introduction

Nowadays, buildings contribute for more than 40% of global energy consumption [1]. According to "The fifth assessment report" of the IPCC, the global energy demand is expected to be doubled by the end of 2050 alongside the increasing of CO2 emission which contributed to 50–150% increased comparing with the baseline scenarios [2]. In other words, building sector could have a great potential for greenhouse gas (GHG) emissions mitigation. Apparently, energy consumption in either new or existing building can be reduced to 30-50% by applying advance technologies or installing the high energy efficient equipment; for instance, smart design, insulation improvement, low-energy appliances, high efficiency heating, ventilation and air conditioning (HVAC) system and conservation habits from building occupants [3]-[6]. In order to achieve the sustainability development, the economic evaluation should be involved for decision making whether which approaches should be implemented [7].

In Thailand, educational building is one of building types that consumes a huge amount of energy. Most electricity consumption in this type of building was distributed for HVAC system followed by lighting system [8]. Due to a raising awareness of global warming, improving energy-related environmental performance in building sector is vital.

This study, therefore, was investigated the energy conservation measures that had been implemented in educational buildings in Thailand in order to make an assessment of both environmental and economic performances. Each measure was evaluated for a level of energy saving and emission reduction potential as well as its cost effectiveness. The results of this study could be useful for decision maker, planner, or building owner to make the strategies on energy efficiency and improve the emission mitigation in study building sector later on. The benefits from this study are not only in environmental aspect but also in an economic aspect as well.

## II. Methodology

### A. Case Studies

In order to make the assessment for the performances of energy and GHG emission, seven types of data were used for the analysis. The categories contained fossil fuel consumption, electricity consumption, renewable energy consumption, water supply consumption, wastewater treatment, solid waste generation and the other related GHG emissions. Each type of data was collected form five educational buildings located in Bangkok.

### B. Assessment of Energy Saving

Data regarding energy conservative measures of each building was gathered for estimating the amount of energy that would be reduced after implementation by using the following equations.

$$ESG_{i,j} = \sum_k ES_{i,j,k} \; / \sum_k A_{i,j,k} \qquad (1)$$

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$$ES = BE_{EC} - PE_{EC} \quad (2)$$

where:

$ESG$ = Energy saving of measure group (kWh/m$^2$/year)
$ES$ = Energy saving of each measure type (kWh/year)
$BE_{EC}$ = Baseline energy consumption (kWh/year)
$PE_{EC}$ = Project energy consumption (kWh/year)
$A$ = Building area (m$^2$)
$i$ = Building type i
$j$ = Measure's group j
$k$ = Measure index

### C. Assessment of GHG Reduction

Emission reduction (ER) obtained from the implementation of energy conservative measures was analyzed through four methodologies which are CDM, namely AMS-II.C, AMS-II.N, AMS-I.A and AM0091. As same as the concept of energy saving assessment, the amount of GHG emissions that could be reduced after such implementation was calculated using the (3) and (4) as followed;

$$ERG_{i,j} = \sum_k ER_{i,j,k} / A_{i,j,k} \quad (3)$$

$$ER_k = BE_{GHG} - BE_{GHG} \quad (4)$$

where:

$ERG$ = GHG reduction of each measure group (kg$CO_2$eq/m$^2$/year)
$ER$ = Emission reduction of each measure type (kg$CO_2$eq/year)
$BE_{GHG}$ = Baseline emission reduction (kg$CO_2$eq/year)
$PE_{GHG}$ = Project emission reduction (kg$CO_2$eq/year)
$A$ = Building area (m$^2$)
$i$ = Building type i
$j$ = Measure's group j
$k$ = Measure index

The description of four CDM methodologies are described as follows:

AMS-II.C: Demand-side energy efficiency activities for specific technologies. This methodology comprises activities that involve the installation of new, energy-efficient equipment (e.g. lamps, ballasts, refrigerators, motors, fans, air conditioners, pumping systems, and chillers) at one or more project sites. Retrofit as well as new construction projects are included under this methodology.

AMS-II.N: Demand-side energy efficiency activities for installation of energy lighting and/or controls in building. This methodology comprises activities in buildings for: (a) Retrofits of existing electric lighting fixtures, lamps, and/or ballasts with more energy-efficient fixtures, lamps, and/or ballasts; (b) Permanent de-lamping of electric lighting fixtures with or without the use of reflectors; (c) Installation of lighting controls, such as occupancy sensors or timers in order to reduce electric lighting lamp operating hours. Only retrofit projects involving direct installation of equipment are eligible. Projects only involving the sale or distribution of efficient lighting systems and/or controls are not included under this methodology.

AMS-I.A: Renewable energy project; Electricity generation by the user. This category comprises renewable electricity generation units that supply individual households, users or groups of households/users included in the project boundary he renewable energy generation units include technologies such as solar, hydro, wind, biomass gasification and other technologies that produce electricity all of which is used on-site/locally by the user, e.g. solar home systems, wind battery chargers. The renewable generating units may be new installations (greenfield) or replace existing onsite fossil-fuel-fired generation.

AM0091: Energy efficiency technologies and fuel switching in new and existing buildings. This methodology applies to project activities that implement energy efficiency measures and/or fuel switching in all types of either new or existing building. Examples of the measures include efficient appliances, efficient thermal envelope, efficient lighting systems, efficient heating, ventilation and air conditioning systems, passive solar design, optimal shading, building energy management systems, intelligent energy metering, and fuel switching, excluding switching to biomass.

### D. Economic Evaluation

To evaluate the cost effectiveness of energy conservative measures, Net present value (NPV) analysis was used in this study. The NPV is calculated by subtracting the investment cost of the implemented measure from the discounted cash flow of energy saving benefit as shown in (5). The measure is considered to be financial worthwhile if the NPV is greater than zero. Moreover, the cost of emissions reduction as expressed in (6) was evaluated to emphasize the fact based on emission-reduction feasibility

$$NPV = \sum_{t=1}^{t} [Ct / (1 + r)^t] - C_0 \quad (5)$$

where:

$NPV$ = Net present value (USD)
$Ct$ = Net cash flow during the year t (USD)
$Co$ = Total initial investment cost (USD)
$r$ = Discount rate (%), assumed at 7% in this study
$t$ = Energy efficiency measure's lifetime (year)

$$AC = [EAC - (ES_k \times EP)] / ER_k \quad (6)$$

where:

$AC$ = Abatement cost (USD/kg$CO_2$eq)
$EAC$ = Equivalent annual investment cost (USD/year)
$ES_k$ = Energy saving from measure index k (kWh/year)
$EP$ = Energy price (USD/kWh)
$ER_k$ = Emission reduction from measure index k (kg$CO_2$eq/year).

## III. Result and Discussions

### A. Building Performances

As presented in Table I, energy consumptions of five study buildings were in a range of 864–2,856 GJ annually, resulting in the energy-related emissions about 44–336 t$CO_2$eq/year. The buildings consumed the energy from the renewable sources which presented the negative value of emission because it produces no emissions while using the alternative sources instead. Based on data availability, two types of refrigerant, namely R134A and R22 were involved in two cases of this study which contributed 67% and 10% of the total emissions of B1 and B5 respectively. It could be implied that a larger amount of building occupants affected the loads of cooling system and consequently required a greater amount of refrigerant. Averagely, the wastewater generation to water supply consumption ratio of study buildings in this study was at 0.85, while the proportion of solid waste generation was 0.01 kg/person/day for B1 and B5, and 0.04 kg/person/day for the remainders. Among 5 case studies, it can be concluded that the best environmental performance was the case B1 since it emitted the lowest emissions intensity either in a unit of total floor area or of building occupants. In addition, as demonstrated in Fig. 1 and Fig. 2, building owners or planners should heavily focus on HVAC system since it contributed to the greatest energy consumption and also the major source of GHG emissions.

TABLE I: INFORMATION, PERFORMANCE AND GHG EMISSION OF EDUCATION BUILDING CASE STUDY

| Category | Unit | B1 | B2 | B3 | B4 | B5 |
|---|---|---|---|---|---|---|
| Total floor area | $m^2$ | 10,640 | 3,350 | 3,914 | 7,400 | 9,512 |
| Building occupants | person/day[a] | 1,756 | 700 | 633 | 480 | 700 |
| **Building performance** | | | | | | |
| Fossil fuel consumption | MJ/year | 579,961 | 565,992 | 452,070 | 287,215 | 438,809 |
| Electricity consumption | MJ/year | 460,080 | 994,043 | 412,420 | 2,224,800 | 1,133,280 |
| Renewable energy use | MJ/year | 415,091 | 0 | 0 | 344,160 | 115,045 |
| Refrigerant | kg/year | 86 | 0 | 0 | 0 | 14 |
| Solid waste generation | kg/year | 5,179 | 7,445 | 5,900 | 5,025 | 2,100 |
| Water supply consumption | $m^3$/year | 7,152 | 6,205 | 12,233 | 5,324 | 6,994 |
| Wastewater generation | $m^3$/year | 5,722 | 5,585 | 9,781 | 4,526 | 6,295 |
| **GHG emission** | | | | | | |
| Fossil fuel consumption | $kgCO_2eq$/year | 35,925 | 35,043 | 27,990 | 17,783 | 27,169 |
| Electricity consumption | | 77,869 | 168,242 | 69,802 | 376,547 | 191,808 |
| Renewable energy use | | -69,908 | 0 | 0 | -57,962 | -19,376 |
| Refrigerant | | 122,980 | 0 | 0 | 0 | 24,616 |
| Solid waste generation | | 12,580 | 19,756 | 14,969 | 12,220 | 5,436 |
| Water supply consumption | | 3,634 | 3,153 | 6,216 | 2,705 | 3,554 |
| Wastewater generation | | -[b] | -[b] | -[b] | 2828.4875[c] | 12038.4225[d] |
| **Total emissions** | $tCO_2eq$/year | 183 | 226 | 119 | 354 | 245 |
| **Emission intensity** | $tCO_2eq/m^2$/year | 0.017 | 0.068 | 0.030 | 0.048 | 0.026 |
| | $kgCO_2eq$/person/day | 0.42 | 1.29 | 0.75 | 2.95 | 1.40 |

[a] Working day of education system in Thailand is 250 days/year.
[b] GHG emission of aerobic wastewater treatment system of B1 - B3 has been accounted for that of electricity consumption.
[c] There is no wastewater treatment system in case of B4.
[d] Wastewater treatment of B1 is an anaerobic filter.

TABLE II: NUMBER OF IMPLEMENTED MEASURES IN FIVE BUILDING CASES STUDY

| Measures | Number of implemented measures | | | | | |
|---|---|---|---|---|---|---|
| | B1 | B2 | B3 | B4 | B5 | Total |
| Cooling efficiency | 2 | 2 | 1 | 2 | 1 | 8 |
| Lighting efficiency | 2 | 3 | 2 | 3 | 1 | 9 |
| Building management | 1 | - | - | 1 | - | 2 |
| Renewable energy | 2 | - | - | 1 | 1 | 4 |
| Energy saving practice | 1 | 1 | 1 | 1 | 1 | 4 |
| Wastewater treatment | 1 | - | - | - | - | 1 |
| Water saving | - | - | - | 1 | - | 1 |
| Solid waste recycles | 1 | - | - | - | - | 1 |

TABLE III: SUMMARY OF ENVIRONMENTAL AND ECONOMIC PERFORMANCES

| Code | Measure's name | Life time (yrs.) | Applicable CDM | ESG (kWh/$m^2$/yr.) | ERG (kg$CO^2$/$m^2$/yr.) | NPV (USD) | GHG abatement cost (USD/kg$CO^2$eq) |
|---|---|---|---|---|---|---|---|
| CE01 | High efficiency spilt-type AC replacement | 15 | AMS-II.C | 20.66 | 11.70 | 77936 | -0.13 |
| CE02 | Spilt-type AC system maintenance | 15 | AMS-II.C | 3.37 | 1.91 | 70383 | -0.25 |
| LE01 | High efficiency LED Lights replacement | 8.5 | AMS-II.N | 3.49 | 1.98 | 29723 | -0.14 |
| LE02 | Lighting efficiency improvement | 8.5 | AMS-II.N | 3.38 | 1.91 | 25298 | -0.25 |
| BM01 | Automatic system control | 8.5 | AMS-I.C | 1.97 | 1.12 | 14618 | -0.27 |
| BM02 | Building energy management system | 20 | AM0091 | 21.18 | 12.00 | 189491 | -0.20 |
| ES01 | Saving practice | 10 | AMS-II.C | 1.17 | 0.66 | 17073 | -0.27 |
| RE01 | Solar cell installation | 25 | AMS-II.A | 13.34 | 7.59 | 31698 | -0.08 |

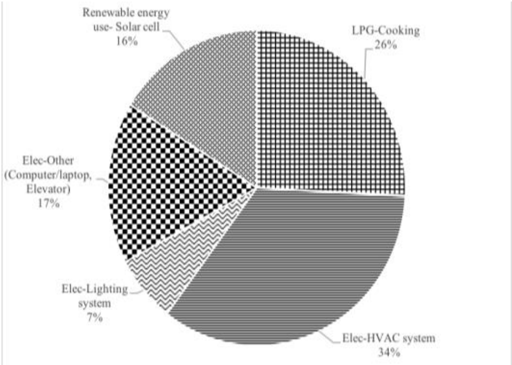


Fig. 1. Proportion of energy consumption.

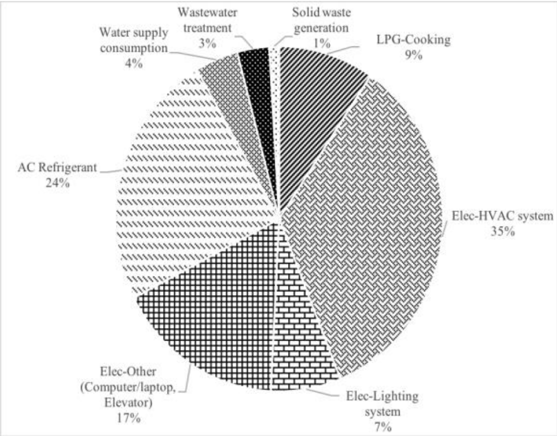


Fig. 2. Proportion of GHG emission.

### *B. Environmental Performance*

Measures of environmental management in building were classified into eight groups and a number of each measure that had been implemented in five buildings are presented in Table II. The results revealed that most appropriate practices were energy-related emissions measures. Therefore, either environmental or economic performances of those measures were analyzed in detail to emphasize its feasibility as presented in Table III. Regarding the results from five study buildings, most buildings applied the AMS-II.C method for increasing the cooling efficiency followed by AMS-II.N while some AMS-I.A and AM0091 methods were implemented for increasing lighting efficiency, enhancing the renewable energy and improving building energy management system. The results also emphasized that building energy management measure (BM02) contributed to the highest potential for energy savings and GHG mitigation followed by the replacement of high efficiency spilt-type AC and solar cell installation.

### *C. Economic Performance*

It turned out that every measure showed a feasibility of implementation as all cases provide a positive NPV. A key factor of economic performance for building improvement was electricity charge which accounts for 0.15 USD/kWh. Moreover, the results of GHG abatement cost also indicated that none of the measures is unfeasible as all measures provide a negative value. Particularly, BM02 portrayed the best option for the energy savings and GHG mitigation improvement of study buildings since it provided the highest benefit not only NPV aspect but also for energy savings and GHG reduction parts as well, followed by CE01, CE02 and RE01.

## IV. Conclusion

This study was aimed to make the assessment for the environmental and economic performances of educational buildings through environmental management measures which implemented in Bangkok. Four CDM methodologies were applied to quantify the amount of GHG mitigation while the cost effectiveness was performed through NPV and GHG abatement cost analysis. The findings illustrated that building energy management system (AM0091) contributed to the greatest potential for improving energy efficiency and GHG mitigation, followed by AMS-II.C (high efficiency spilt-type AC replacement) and AMS-I.A (solar cell installation) method. Whilst the least investment cost required to reducing one kilogram of $CO_2$eq was denoted to saving practices and automatic control system. In addition, building owners or decision makers should consider on HVAC system intensively as it consumed high amount of energy and produced a huge amount of GHG emissions. To summarize, the building energy management system should be suggested for the implementation for every building as these options provide the best benefits in all three aspects at once. The information regarding the potential of the energy efficiency and GHG mitigation improvement along with the cost effectiveness of each measure would be useful for decision makers to make the strategies for building sector later on.

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