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PERFORMANCE OF AIR CONDITIONING SYSTEM IN EDUCATIONAL BUILDING FOR ENERGY CONSERVATION

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ABSTRACT: Nowadays, the building sector has played an important role in global energy consumption. In Thailand, about half of energy used in building is generally supplied for cooling systems. The objective of this study, therefore, is to investigate the environmental performance of an air-conditioning (AC) system for an educational building and to propose strategies for mitigating GHG through energy efficiency measures toward campus-wide sustainable energy policy. The results of this building case study demonstrate that the existing AC system consumes about 70% of total energy consumption. As a consequence of the low energy efficiency of the existing AC system, the whole building's performance has failed to meet the standard of Thai's building energy code. To improve building energy efficiency, aside from replacing the current AC system with a high-efficiency AC system that would be needed, implementing alternative energy conservation measures, for instance changing window panes, walls, and roof tile materials and installing thermal insulation, were proposed to quantify the amount of energy savings as well as GHG emissions reductions. The findings will be useful for building owners, architects and policymakers as a guideline for demonstrating a building's energy-efficiency.

Keywords: Environmental performance, Energy conservative measure, Air-conditioning system, Educational building

1. INTRODUCTION

Due to increasing global concern about climate change, energy efficiency and environmental remediation have broadly become main areas of research. One of the main issues concerning the effort to limit global temperature rise to only 2 degrees Celsius above pre-industrial levels is the building sector since it consumes a huge amount of energy and resources and emits a large amount of greenhouse gas (GHG) [1]-[2]. In tropical countries, increased use of air conditioner to maintain thermal comfort in buildings is the main cause influencing an increasing of energy demand whereas increased use of heater is a key factor for the temperate countries [3]-[5]. Accordingly, it could be implied that high potentials of either energy saving or GHG emission reduction in building can be achieved through energy improvement options for Heating, Ventilating, and Air Conditioning (HVAC) system. Numerous studies have recently validated that coupling with changing occupant habits, implementing advanced cleaner technologies and high energy efficiency equipment will help reduce about 30-50% of total energy consumption for either new or existing buildings [6]-[9].

In Thailand, the final energy consumption of the domestic building sector has increased rapidly. Such consumption accounted for 22% of the total national energy consumption in 2017 with a growth rate of 82% over the last two decades [10]. To cope with a concern of energy security for such a huge demand over scarcity resources sufficiently, the Thailand's Ministry of Energy has issued Ministerial Regulation stipulating the type and size of buildings and standards criteria and methods of designing energy conservation building, B.E. 2552 (2009) and provided for the monitoring of designated commercial buildings that consume more than twenty-million megajoules of power energy equivalent annually [11]. Among the six categories of designated commercial building, data obtained from Department of Alternative Energy Development and Efficiency (DEDE) demonstrated that the stock of educational institution building accounted for 9% which consumed around 15% of total energy demand for buildings [12]. Consequently, research on ways to improve the energy efficiency of this type of building would definitely contribute positive impacts on energy security significantly. Chavalparit and Limphitakphong [13] have evaluated the energy efficiency and environmental performance of buildings in Bangkok and emphasized that most of the energy use in the educational building was attributed to electricity consumption for HVAC system, resulting in the greatest portion of GHG emission as a consequence. Thaipradit [14] has provided evidence demonstrating a significant impact of applying building insulation materials on the performances of energy and environment in educational buildings of Thailand. Chaiyat [15] has applied the concept of using phase change material for improving the cooling efficiency of an air conditioner and found that the modified air-conditioner could decrease the annual electrical consumption by about 1.13 MWh while having a payback period for modifying equipment of 4.15 yr.

In addition, since the Thai Ministry of Energy has pledged to reduce GHG emissions around 20-25% by 2030 at the 21st conference of the parties, commercial buildings have become a major contributor in reducing such a number of reductions through energy efficiency measures [16]. This study, therefore, was aimed at investigating the environmental performance of existing air-conditioning (AC) system for educational building and to propose strategies for mitigating GHG through energy efficiency measures toward campus-wide sustainable energy policy. Besides applying advanced technology and replacing high energy efficiency equipment, changing building envelopes were also evaluated to identify alternative options for improving existing buildings, based on either an environmental or economic performances perspective. The information provided from the findings of this study can be useful for policymakers and building planners in determining strategies for either reducing energy demand and GHG emissions or saving expenditures of educational institution.

2. MATERIALS AND METHODS

2.1 Building Description

Characteristics of a 5-storey educational building of Chulalongkorn University used to perform in this study are described in Table 1. The buildings case study is located in the heart of Bangkok at 13.92 latitudes and 100.6 longitudes with a range of dry-bulb temperature of 19.0 – 37.2 °C and humidity ratio of 11.2 – 28.7 gw/kgda throughout the year [17].

2.2 Energy Efficiency of Air Conditioning System

In this building case, only split type air conditioner was installed entirely. To evaluate the electrical consumption efficiency of AC system, two main components of such air conditioner namely condensing unit and fan coil unit as presented in fig. 1 are involved for investigating three indicators including cooling performance (CP), coefficient of performance (COP), and energy efficiency ratio (EER) following Eq. (1) – (2), Eq. (3) and Eq. (4) respectively. An important measure for measuring AC efficiency directly is COP since it demonstrated the work gained from power input, while the EER is illustrated the cooling performance compared to the outdoor temperature. Either the higher of COP or EER, the more efficient the AC system is indicated.

Table 1 The basic parameters of case study educational building

Building parameters	Specifications
Floors	5 floors above ground
Gross floor area	1,862.28 m^2
Air-conditioned area	1,195.43 m^2
Structure	Concrete
Envelope	Brick and curtain wall combination
Glass	Clear flat glass
Roof	Flat roof, concrete slab

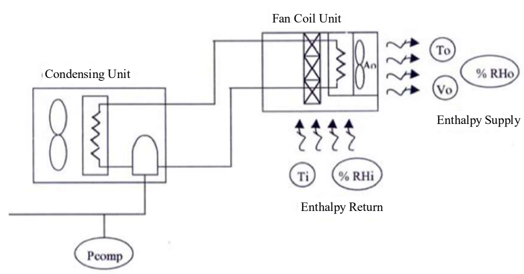


Fig 1 Positions for measuring split type AC system efficiency

$$CP = P_{comp}/CL \quad (1)$$

$$CL = 5.707 \; x \; 10^{-3} \; x \; A \; x \; V \; x \; 60 \; x \; (H_r - H_s) \quad (2)$$

$$COP = \Delta h_{out}/\Delta h_{in} \quad (3)$$

$$EER = [4.5 \; x \; A \; x \; V \; x \; 60 \; x \; (H_r - H_s)]/P_{comp} \quad (4)$$

Whereas;

P_{comp} = Power input into the compressor (kW), inspecting at condensing unit by the power meter

CL = Cooling load (TR), inspecting at fan coil unit

A = Cross-sectional area (m^2)

V = Velocity (m/s)

H_r = Enthalpy Return (kJ/kg dry air), referring to the psychometric chart

H_s = Enthalpy Supply (kJ/kg dry air), referring to the psychometric chart

Δ_{out} = Difference of enthalpy at fan coil unit (kJ/kg)

Δh_{in} = Difference of enthalpy at condensing unit (kJ/kg)

2.3 Energy Simulation

To identify the potential of alternative options for improving building's energy efficiency, Building Energy Code (BEC) software version 1.0.6 developed by DEDE in accordance with the Ministerial Regulation on type or size of buildings and standards criteria and methods of designing energy conservation buildings B.E. 2552 (2009), was used in this study to estimate the amount of energy savings compared with the current consumption. Data input in the program is classified into 6 categories, including building envelope, lighting system, AC system, photovoltaic (PV) system, hot water (HW) system, and other equipment. However, since there are no PV and HW systems in this case while lighting system and others equipment only share a little portion of energy consumption, this study, therefore, was focusing on the AC system and envelope materials that are related to heat transfer through building envelope and building's energy demand. Furthermore, four options for improving the energy efficiency of the building were examined to signify a key building material resulting in better building performance as presented its properties in Table 2 - 3.

Table 2 Properties of opaque materials

Type		Thermal Conductivity (W/m·K)	Density (kg/m^3)	Specific Heat (kJ/kg·K)
Ceiling Insulation Materials	PVC Gypsum	0.211	684	1.09
	Aluminum Foil Gypsum	0.322	745	1.09
	Polyurethane	0.023	24	1.59
	Glass Wool (Stay Cool)	0.039	12	0.96
Wall Materials	Autoclaved Aerated Concrete	0.476	1,280	0.84
	Concrete Block	0.546	2,210	0.92
Roof Tile Materials	Concrete Profile Tiles	0.993	2,400	0.79
	Asbestos Cement Corrugated	0.395	2,000	1.00

Table 3 Properties of transparent materials

Glass Type	Thickness	Visible Ray		Solar Energy			U-value	SHGC
	m	Reflectance	Transmittance	Reflectance	Transmittance	Absorption	w/m^2	
Tinted Glass	0.006	7.0	0.760	5.0	49.0	46.0	5.74	0.6
Solartag (TS560)	0.006	5.2	0.361	4.8	21.9	73.3	5.35	0.4

2.4 Environmental Performance Analysis

Due to global concern about climate change, the environmental impact of energy consumption was demonstrated in terms of CO_2 emission through the following equation (Eq. 5);

$$ER = (BE_{Ec} - PE_{EC}) \times EF_{GRID} \quad (5)$$

Where ER is emission reduction of each measure ($kgCO_2$/yr). BE_{EC} refers to baseline energy consumption (kWh/yr) and PE_{EC} represents project energy consumption (kWh/yr). EF_{GRID} stands for emission factor of electricity production, which is approximately 0.6093 $kgCO_2$/kWh for Thai grid production [18].

2.5 Economic Performance Assessment

A payback period (PB) analysis was used in this study as demonstrated in Eq. (6) to assess the economic performance of each energy efficiency improvement measure. A trade-off between investment cost and energy expenditure savings will help signify and prioritize the possible measures for implementation. When the total investment cost is paid by the saving of energy cost, it is a point of break-even, which thereafter entails no monetary loss from implementation.

$$PB = IC/ECS \quad (6)$$

Where PB is payback period (years). IC refers to investment cost of implementation (U.S. Dollar).

ECS represents energy cost saving throughout a year after implementation (U.S. Dollar/year).

3. RESULTS AND DISCUSSIONS

3.1 Energy Consumption of Educational Building: A Case Study

Through 12 months of data collection, the building case study consumed about 127,489 kW of electricity, which approximately 71% of this total power consumption was attributed to the AC system. Such a portion is quite high compared with the average energy consumption proportion of educational buildings (59%) presented by Phupadthong [9]. This indicates that the efficiency of the AC system in this case study is probably low, resulting in consuming a higher amount of energy than the typical case. An energy efficiency evaluation of AC system also emphasized that among all the AC equipment, only two of them comply with the Thai industrial standards as presented in Table 4.

Table 4 Energy performance of air conditioning system in the building case study

No.	Capacity (Btu)	Ideal Performance* (kW/TR)	Actual AC Efficiency			Comply with TIS**
			CP	COP	EER	
1	12000	1.17	1.66	2.13	7.25	FAIL
2	36000	1.13	2.89	1.22	4.15	FAIL
3	12000	1.17	1.70	2.07	7.05	FAIL
4	48000	1.13	1.23	2.86	9.76	PASS
5	30000	1.16	5.44	0.65	2.20	FAIL
6	12000	1.20	3.94	0.89	3.05	FAIL
7	36000	1.13	2.77	1.27	4.33	FAIL
8	38000	1.14	1.22	2.90	9.87	PASS
9	30000	1.16	9.15	0.38	1.31	FAIL
10	18000	1.25	2.14	1.65	5.62	FAIL
11	30000	1.16	1.62	2.18	7.42	FAIL
12	36000	1.13	2.05	1.72	5.87	FAIL
13	12000	1.10	2.07	1.70	5.78	FAIL
14	12000	1.17	6.00	0.59	2.00	FAIL

*To validate the measurement, CP value of actual AC efficiency shall higher than ideal performance.
**COP and EER should not less than 2.82 and 9.60 respectively to pass the Thai industrial standard [19].

In addition, DEDE building regulations define a suitable level of overall thermal transfer value (OTTV) and residential thermal transfer value (RTTV) at 50 and 15 watts/m^2 for an educational building. The low energy efficiency of the existing AC system in this study, apparently, lead the whole building performance to fall below the standard of this regulation.

3.2 Replacement of High-Efficiency Air Conditioning System

Because the current AC system plays such an important role in the building's energy demands and seemingly caused the building to fall below the standard. Based on an assumption that every AC equipment that has have become obsolete or declines in performance will be replaced with a high-efficiency AC at the same capacity, the result demonstrated that to replace all low-efficiency AC, such implementation requires an investment of 39,224 USD for obtaining a saving of energy consumption by 25,886 kWh a year in return, converting to GHG emissions reduction around 15,772 kgCO_2e/yr. The break-even point of each AC capacity types, as illustrated in Fig.2, will be 6.3, 6.6, 21.1 and 30 yrs. for replacing 12000 Btu, 18,000 Btu, 30,000 Btu and 36,000 Btu, respectively.

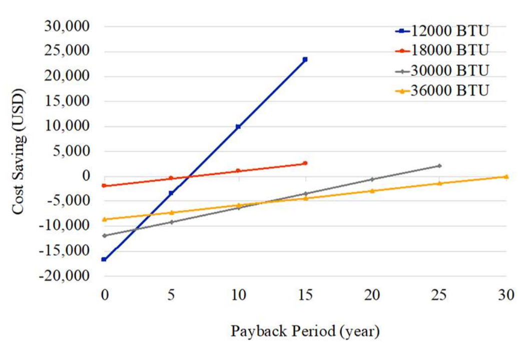
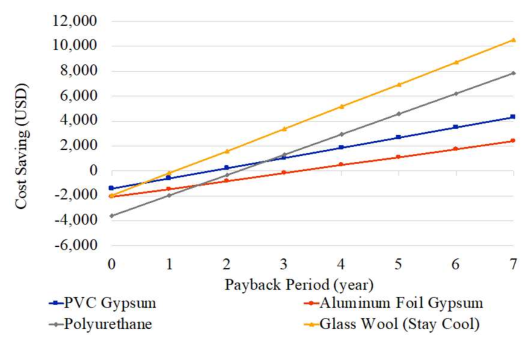


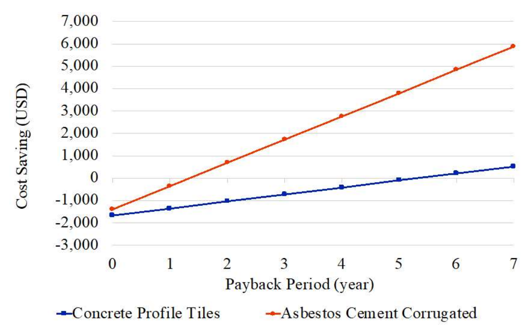
Fig 2 Economic assessment for air conditioning system replacement

3.3 Alternative Options for Improving Energy Efficiency of Buildings

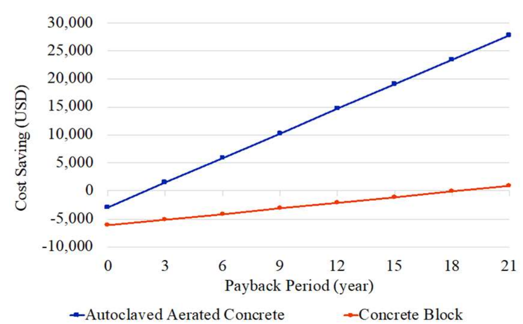
Besides changing the AC system, which requires a payback period for more than 6 years, alternative options for improving the energy efficiency of buildings should be examined. Figure 3 illustrated the payback period for implementing each measure of the four energy efficiency improvement options described in Table 2-3. It was found that the shortest payback period of each material category is installing polyurethane insulation above the ceiling, using autoclaved aerated concrete instead of bricks, roofing with concrete profile tiles, and installing tinted glass. The best 4 measures, therefore, were integrated to re-investigate the maximum level of energy demand reduction as well as GHG reduction through envelope materials improvement. The result as presented in Table 5 revealed that more than 22 MW/yr. of electricity will be saved and about 13,869 $kgCO_2e$/yr. will be reduced if these four measures are implemented together. Moreover, it will help increase the building's performance to meet the code of designated building regulation eventually.



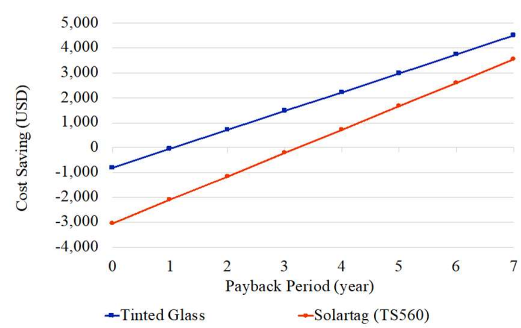
(a) Ceiling Insulation Materials



(c) Roof Tile Materials



(b) Wall Materials



(d) Glass Materials

Fig 3 Economic assessment for improving building envelope materials

Table 5 Performance of improving existing building through envelope materials

Material Type	Investment Cost (USD)	Energy Saving Quantity (kWh/yr.)	Energy Saving Expenditure (USD/yr.)	Payback Period (yr.)	GHG reduction ($kgCO_2e$/yr.)
Tinted Glass	801.74	5,138.6	688.22	1.1	3,131
Polyurethane	3,607.41	11,108.2	743.87	2.2	6,768
Autoclaved Aerated Concrete	2,934.87	9,951.6	733.06	2.0	6,064
Concrete Profile Tile	1,665.75	2,125.2	59.07	5.3	1,295
Total	**6,845.32**	**22,762,2**	**1,676.72**	**2.0**	**13,869**

Note: Electricity charge is about 0.147 USD/kWh

4. CONCLUSION

A large portion of final energy is attributed to the building sector and its demand is going to increase in the near future abruptly. Energy audit to monitor and help manage buildings' energy performance is vital. The performance of the building case at Chulalongkorn University was investigated to identify hotspots and to propose strategies for mitigating GHG. The findings revealed that the efficiency of the air conditioning system was poor as most equipment failed to meet the Thai industrial standards. Either a highly efficient air conditioner replacement or improving building envelope should be implemented to amend this. The initiatives on considering performance-based energy efficiency measures can contribute to campus-wide sustainable energy policy. Further actions on monitoring energy performance and its improvement and future research on other factors influencing energy consumption and GHG emission from this and other buildings are needed, otherwise, this small-scale energy assessment will have a little positive effect on Thailand's environmental sustainability.

5. ACKNOWLEDGMENTS

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