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Energy saving technique for cooling dominated academic building: Techno-economic analysis of its application

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HIGHLIGHTS

- Energy saving strategies in centralized HVAC academic building are demonstrated using system simulation approach.
- Technical analysis of the existing and proposed system, is done and energy saving potentials are identified.
- Economic evaluation proves the superiority of new system on the centralized air conditioning system.

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ABSTRACT

Adaptive cooling technique has been proposed previously, as an energy efficient strategy for a centralized HVAC system in a tropical environment. It served single or multi zone buildings by considering both the occupancy pattern (occupied and unoccupied periods) and the local weather conditions. This technique demonstrated considerable annual energy saving potential, however, the technical consequence and economic evaluation for its application have not been provided. This paper aims to analyze the technical and economical feasibility of the proposed technique for an academic building in Universiti Teknologi PETRONAS. It showed that a dual-duct dual-fan system was required to maximize technical feasibility of the proposed technique due to huge cooling load gap, during occupied and unoccupied periods. At the end, an economic evaluation by using net present worth (NPW) method and 3 financing scenarios were performed by considering the dual-duct dual-fan system. With an assumption of 10 years service time, NPW value of the proposed technique was RM176,404 and hence, it became evident that the proposed adaptive comfort technique was economically feasible.

1. Introduction

Energy saving is defined as an effort to reduce unnecessary energy consumption as by-product of the required energy consumption or to minimize the gap between required energy consumption and final energy consumption. This effort is not costless action; indeed, it needs a noticeable effort that should consider two economic values i.e. private economic value and public economic value. The first value is to ensure that the effort brings utility and private profit while the second value is to give benefits for environment and public goods [1,2]. In general, any energy saving strategies proposed should accommodate these values to ensure the effectiveness, hence, can be considered for the application [3]. In case of high investment cost strategy, an economic evaluation method, i.e. net present value (NPV) method, is required to explain economic feasibility [4].

Energy saving strategy is required in most residential and commercial buildings in Malaysia which consume about 13% of total energy consumption and 48% of electricity consumption. This strategy is one of the focuses of Malaysian government as anticipation to its depleting energy resources [5]. Any strategy to reduce energy consumption should be focused on factors which have significant influence on the total energy consumption. In a building, these factors can be grouped into 3 categories; building envelope, internal conditions, and building service system [6–8]. Strategy that focused on first group should be done from the design stage and would be hard to be implemented on existing building for some extend especially when major changes are required. On the other hand, adjusting internal conditions (i.e. indoor temperature, indoor humidity, etc.) can be the easiest way to get energy saving with nearly zero investment [2]. However, the degree of adjustment is limited to the building service system flexibility (i.e. the HVAC system) or major changes of the system are required for

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Nomenclature

C_o	loss coefficient
D	diameter, ft
f	friction loss
L_e	equivalent length, ft
RLH	room latent heat, kJ/h
RH_r	indoor relative humidity,%
$RH_{r,sp}$	relative humidity set point,%
RH_s	supply air relative humidity,%
RSH	room sensible heat, kJ/h
$RSHF$	room sensible heat factor
T_c	comfort temperature, °C
T_r	room temperature measured
T_{rm}	mean monthly outdoor air temperature, °C
$T_{r,sp}$	room temperature set point, °C
T_s	supply air temperature, °C
M_{sa}	supply air flow rate, kg/s
$\Delta P_{f,u}$	duct friction loss per unit length, Pa/m
ΔP_t	total pressure loss, Pa
ΔT_{ss}	temperature difference between supply air and space air, °F
$\Delta \omega_{ss}$	humidity difference between supply air and space air lb/lb.
Q_{EQUIP}	cooling load from equipment
Q_{ENV}	cooling load from building envelope
Q_{LAT}	latent cooling load
Q_{PEOPLE}	cooling load from occupant
Q_{LIGHT}	cooling load from artificial lighting
Q_{VENT}	cooling load from ventilation air
Q_{INF}	cooling load from infiltration air
$Q_{MACHINE}$	cooling load from machine
AA	discrete payment
i	interest rate

further adjustment. This HVAC system is one of major energy consumer in building that responsible for 40–60% of the total energy consumption [9].

It has been showed that widening or adjusting allowable indoor temperature would strongly influence cooling requirement in the built environment [4,10,11]. The recent advance is to apply adaptive comfort approach for widening the acceptable indoor temperature without scarifying people's comfort [12–15]. The temperature determined from the study is widely known as adaptive comfort temperature (ACT). The temperature is strongly influenced by local outdoor environment and can be modeled as an adaptive comfort model (ACM) which may has linear function to the local outdoor temperature [16]. Several experiments have been conducted to determine ACM for naturally ventilated (NV) [17] and air conditioned (AC) building [18]. The results showed that ACT for AC building was lower than that for NV building.

In a building with dynamic occupancy pattern, there are occupied and unoccupied hours. In case of room air conditioner (RAC), we can easily turn it off to save the energy during unoccupied hours. However, it is not possible for centralized HVAC system which serves multiple rooms since the occupancy pattern is different for each room. Separate control for ventilation air rates during occupied and unoccupied hours showed reasonable daily electrical energy saving up to 28.3% [19]. It implied that unoccupied hours resulted in significant electrical energy loss. In air conditioned building, separate indoor temperature set points for occupied and unoccupied periods showed energy savings of 25%, 37%, and 46% for kindergarten, mosque, and polyclinic building, respectively [20].

Due to fluctuation of ambient conditions during summer and winter seasons, dual indoor temperature set points for both the seasons would reduce cooling/heating energy requirement [21]. However, monthly indoor temperature set points was necessary to be adopted in order to increase the comfort conditions throughout the year. It gives an indication that comfort conditions fluctuate according to the ambient conditions and fixed indoor temperature set point would result in higher energy consumption than monthly indoor temperature set points. An application of monthly-fixed indoor temperature setting could save both cooling and heating energy in the range of 26.8–33.6% compare to yearly fixed setting [11].

Application of ACM to determine indoor temperature set point in a building reduced greatly energy consumption of the HVAC system. In Hong Kong, the application of monthly indoor temperature set points using ACT logarithm showed energy saving as much as 7% [22]. In Australia, case studies showed an estimation of 40–45% energy can be conserved by using the use of ACM [23]. Other related studies showed agreement to this result [24–27].

Previously, the author also suggested adaptive cooling technique to get energy saving from the HVAC system by considering the occupancy pattern (occupied and unoccupied periods) and outdoor conditions [28]. The technique was developed by using adaptive comfort approach and according to the local weather conditions (Malaysia). The simulation results showed energy saving up to 305,105 kW h for the studied building. However, the technical consequence and economic evaluation have not been provided. Since, any energy saving strategy or technique would have by-product or technical consequence and should give both technical and economic benefit, techno-economic analysis is required to ensure technical and economic feasibility (as explained above) for the application. Therefore the aims of this paper are to asses and analyze both economical and technical aspects of the proposed system including its by-product.

2. Methodology

The building considered in the work was a modern academic building with large glazing area in Universiti Teknologi PETRONAS. The building had 3 levels and contained offices, classrooms, laboratories, and mechanical workshops. Each of the room had specific occupancy pattern depending upon the type of the rooms. A centralized HVAC system with 2 AHU on each floor was used to provide indoor thermal comfort for all of the rooms. More detail information about the building envelope, occupancy pattern, and the centralized HVAC system can be seen in the previous work [28].

Technical analysis in this work was focused on technical consequence of the proposed adaptive cooling technique prior to its application. Equal friction duct sizing method was considered in the analysis. For economic analysis, net present worth (NPW) method was used as an indicator for the economic feasibility of the proposed technique. Under this method, expected rate of return is taken into account. The method also provides information whether the proposed work is profitable or unprofitable including the value of money for whole service lifetime of the system. These two methods are explained in detail as below.

2.1. Equal friction duct sizing method

Equal friction method is a common method for duct sizing in practice due to its simplicity and flexibility. Under this method, the air duct is sized so that friction loss per unit length $\Delta P_{f,u}$ for