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ECONOMICAL STUDY OF RETROFITTING UNIKL's LABORATORY WITH DOUBLE-GLAZED WINDOW & CEILING INSULATION

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ABSTRACT

In order to reduce CO_2 greenhouse gas emissions from fossil fuel power plants the reduction of energy consumption through energy efficiency is a promising avenue. The cooling energy demand of a building in a hot and humid climate like Malaysia contributes a lot to the total energy consumption with air conditioners consuming a reported 57 % of the electrical energy in Malaysian office buildings. A UniKL-MICET laboratory was chosen to test the effect of acrylics sheet as a second layer of a single-glazed window and rock mineral wool as a ceiling insulation on the specific electricity consumption (SEC) of the air conditioner before and after retrofitting. The temperature set-point of the air conditioner throughout the study was 16 °C. The SEC was reduced by 3.8 % when upgrading the windows from single glazing unit (SGU) to double glazed units (DGU), while the SEC was reduced a further 2.4 % when insulating the ceiling too (DGU+CI). In addition, the temperature of the air conditioned lab decreased after retrofitting (DGU+CI) by 2 °C to 4.2 °C depending on location within the lab. Thus, further electricity savings can be expected if the set-point is raised to match the original temperature of the lab. The cost of electricity can reduce to 3.75% per year after retrofitting, with ROI estimated approximately 12 years' time.

Keywords: double-glazed, ceiling, mineral wool, insulation, air conditioner energy consumption.

INTRODUCTION

The possibly of the shortage of the energy in the future, the greenhouse gases effect on global warming makes the energy issues more important. The cooling demands in the hot and humid country like Malaysia contribute to high energy consumptions and increasing cooling bills due to rising fuel cost.

To achieve desired thermal comfort, the occupants in the building use air conditioning to lower the indoor temperatures and humidity. In a survey from (Mahlia *et al.* 2011) it was found that the usage of air conditioners contributes 42% of the electricity consumption of commercial and 30 % from residential buildings. Commercial buildings are not only a major consumer of energy, but also a significant indirect contributor of CO_2 emissions (Saidur, 2009). The main contributor of total energy consumption in office buildings was found to be due to air conditioning (57 %), followed by lighting (19 %), lifts and pumps (8%) and others equipment (6%) (Saidur, 2009).

An energy audits for office buildings in Malaysia was carried out by Pusat Tenaga Malaysia (PTM) and revealed that the majority of Malaysian office buildings had a building energy use index (BEI) in the range of 200 to 250 kWh / m^2 / yr (Aun, 2009).

The transformation of the SGU to DGU is a widely known green approach to reduce SEC in air conditioned buildings. Double or triple glazing window aim to reduce the heat transfer (convection, conduction) through the glazing, since solar heat transmitted through the window affects the cooling and heating energy consumption of buildings.

In order to further reduce heat transfer through the building envelope, the ceiling may also be insulated. The insulation materials delay the flow of heat into the building due to their high thermal resistance, which reduce dependence on air conditioners to cool buildings. A review article stated that polyurethane, fiberglass, polystyrene, polyethylene and vermiculite are the most common building insulation materials used today (Takashi *et al.* 2013).

This paper aims to study the effect of the simple DGU and ceiling insulation on temperature and SEC of an air conditioned laboratory at UniKL MICET.

LITERATURE REVIEW

The low energy demand of genuine green buildings creates "The Sustainability Revolution". The steady increase of CO_2 concentrations in our earth's atmosphere, to levels unseen in hundreds of thousands of years, results in unprecedented global warming, makes the transition to a future based on renewable, non-carbon based energy sources ever more urgent. Since residential and nonresidential buildings contribute about 40 % of the world's CO_2 emissions, the focus of carbon reduction policies, programs, and actions must necessarily be on the built environment (Yudelson, 2010).

Numerous studies concerning the energy demand and building envelope have been conducted. (Li *et al.* 2009) reported that the most effective method is the use of energy efficient windows by improving the window material and shading devices as to prevent the heat transfer from hot outdoor to air conditioned indoor environment. (Takashi *et al*. 2013) reported that installation of additional panes as a window technique appears promising for creating a comfortable and energy-efficient living environment. Since the outdoor temperature and solar radiation significantly influence the indoor thermal environment through openings, window renovation will improve the indoor climate and reduce the cooling and heating loads.

A theoretical analysis on the effect of ceiling and pitch insulation on thermal performance of buildings in Malaysia concluded that the position of insulation at pitch roof would provide a better thermal condition in attic during daytime and insulation at ceiling would enhance indoor thermal condition (Halim *et al*. 2011). The theoretical analysis was supported by (McKay, 1987) found that at low heat loads and with typical office use, the addition of insulation reduces energy consumption.

The effectiveness of the insulation depends on the location as well as the thickness that determines the R-value and U-values of the material and construction. These are used to appraise the thermal performance of a building material or assembly. R-values represent the resistance of heat transfer through a building material. The higher the R-value, the greater is the resistance and the insulating value (Halim *et al.* 2011).

Figure-1 shows the three heat transfer mechanism through a DGU. Overall heat flow from the warmer to cooler side of a window unit is a complex interaction of all three basic heat transfer mechanisms - conduction, convection, and long-wave radiation for windows, a principle energy concern is their ability to control heat gain. A window assembly's capacity to resist this heat transfer is referred to as its insulating value, or U-value (Anonymous, 2009).

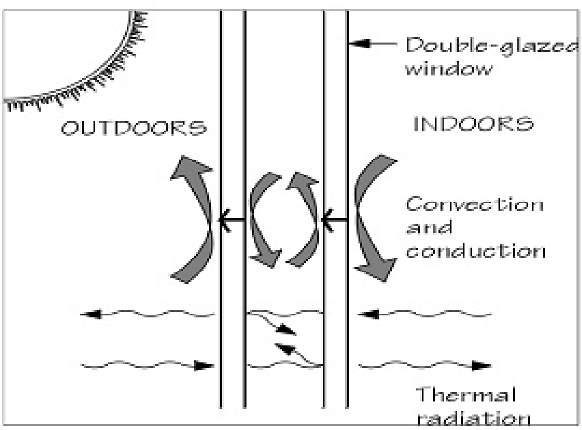

Figure-1. Three basic heat transfer mechanisms through DGU.

METHODOLOGY

Room and System Description

Laboratory 16 at UniKL MICET housing a smaller, air conditioned internal lab was chosen for this study because it is representative for a number of similar labs on this campus. It is commonly used as a sample testing lab with numerous analytical instruments requiring continuous air conditioning. The dimension of the lab is 8.72 m (length) x 2.0 m (width) x 2.73 m (height) with a total volume of 47.6 m^3, a floor area of 17.4 m^2 and a window-to-wall (WWR) ratio of 0.2. Windows 1 and 2 (Figure-2) are facing the big, non-air conditioned lab consisting of single-pane float glass with aluminium frame (116.5 cm high and 57 cm wide for each window partition). The thickness of the ceiling panels is 5 mm.

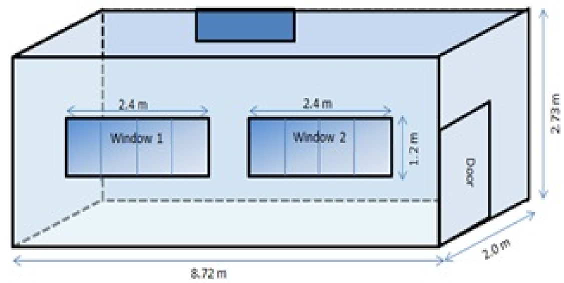

Figure-2. Internal air conditioned lab dimension.

The lab is equipped with an air conditioner by Dunham Bush (single phase, 3 HP) with a rated cooling capacity and power of 3 – 15 kW respectively.

The SGU was converted to a DGU using acrylic panes of 3 mm thickness. As a ceiling insulation, the blanket type of mineral wool (Roxul, Melaka) was used with 50 mm thickness and a density of 50 kg / m^3.

The parameters measured in this study were the temperature of non-air conditioned large and air conditioned internal laboratory number 16, surface temperatures of SGUs and DGUs, as well as SEC of the air conditioner.

The data logger (HOBO-U12-012) with TMC-6-HE temperature sensors were set to monitor the internal, external and window pane surface temperatures at 15 min intervals. In addition, LASCAR Data Logger (EL-USB-2-LCD) was used to measure humidity and temperature of the external and internal lab. The LASCAR Data Logger used to measure the indoor and outdoor temperatures.

The SEC of the air conditioner was monitored manually at 15 min intervals Monday to Friday from 8.30 am to 5.30 pm using a digital energy meter (Andeli Group Co. Ltd, ADM-25S) fitted to the power switch of the single-phase AC unit.

Data Analysis

The respective U-values of SGU, DGU and CI were determined using following equation:

$$U = 1/R_T \quad (1)$$

$$R_T = \sum_{i=1} R_i \quad (2)$$

$$R_i = \frac{d}{k} \quad (3)$$

Where R_T is the total resistance [m^2K/W], R_i is resistance of each window layer [m^2K/W], d is thickness [m] and k is thermal conductivity [W/mK].

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The tariff from Tenaga Nasional Berhad (TNB) use as reference to calculate the electricity cost saving and ROI.

RESULTS AND DISCUSSIONS

Table-1 summarises the calculation of U-values for SGU and DGU. The heat transmission value of glazing was estimated to decrease from 5.99 W/m^{2}K (SGU) to 2.83 W/m^{2}K (DGU). This also applied to CI, table 2 summarises the calculation of U-values for ceiling before and after retrofitting. The value decreases from 4.26 W/m^{2}K (without CI) to 0.62 W/m^{2}K (CI).

This suggests that the greater the window heat transfer resistance the better its insulating value and the lower the SEC of the air conditioner.

The temperature and SEC data before retrofitting were collected from 30th September to 4th October 2013, followed by collecting data after retrofitting the internal laboratory with DGU (21/10/2013-25/10/2013) and lastly with CI (28/10/2013- 01/11/2013), and are summarised in Tables-3 and 4.

The SEC of the air conditioner was determined from the slope of a linear trend line equation fitted onto experimental data of AC energy consumption versus time (Figures-3 and 4).

Table-1. Calculation of U-value of windows.

Single-Glazed Window				
Layer	**Thickness, d (m)**	**Thermal Conductivity, k (W/mK)**	**Resistance, R (m^2K/W)**	**Reference**
Outside surface	N/A	N/A	0.044	[8]
Glass window pane	0.003	0.9	0.003	[7]
Inside surface	N/A	N/A	0.12	[8]
Total resistance, R_T **U-value for single glazed window = 1/ R_T**			**0.167m^{2}K/W** **5.99 W/m^{2}K**	
Double-Glazed Window				
Layer	**Thickness, d (m)**	**Thermal Conductivity, k (W/mK)**	**Resistance, R (m^2K/W)**	**Reference**
Outside surface	N/A	N/A	0.044	[8]
Glass window pane	0.003	0.9	0.003	[7]
Air Gap	N/A	N/A	0.17	[7]
Acrylic sheet	0.003	0.19	0.016	[7]
Inside surface	N/A	N/A	0.12	[8]
Total resistance, R_T **U-value for DGU = 1/R_T**			**0.353m^{2}K/W** **2.83 W/m^{2}K**	

*N/A= not applicable

Table-2. Calculation of U-value of ceilings.

Ceiling without Insulation				
Layer	**Thickness, d (m)**	**Thermal Conductivity, k (W/mK)**	**Resistance, R (m^2K/W)**	**Reference**
Outside surface	N/A	N/A	0.055	[8]
Gypsum board ceiling	0.003	0.17	0.018	[7]
Inside surface	N/A	N/A	0.162	[8]
Total resistance, R_T **U-value for single glazed window = 1/ R_T**			**0.24 m^{2}K/W** **4.26 W/m^{2}K**	

Ceiling with Insulation				
Layer	**Thickness, d (m)**	**Thermal Conductivity, k (W/mK)**	**Resistance, R (m^2K/W)**	**Reference**
Outside surface	N/A	N/A	0.055	[8]
Rock mineral wool	0.05	0.036	1.389	[7]
Gypsum board ceiling	0.003	0.17	0.018	[7]
Inside surface	N/A	N/A	0.162	[8]
Total resistance, R_T **U-value for single glazed window = 1/ R_T**			**1.62 m^{2}K/W** **0.62 W/m^{2}K**	

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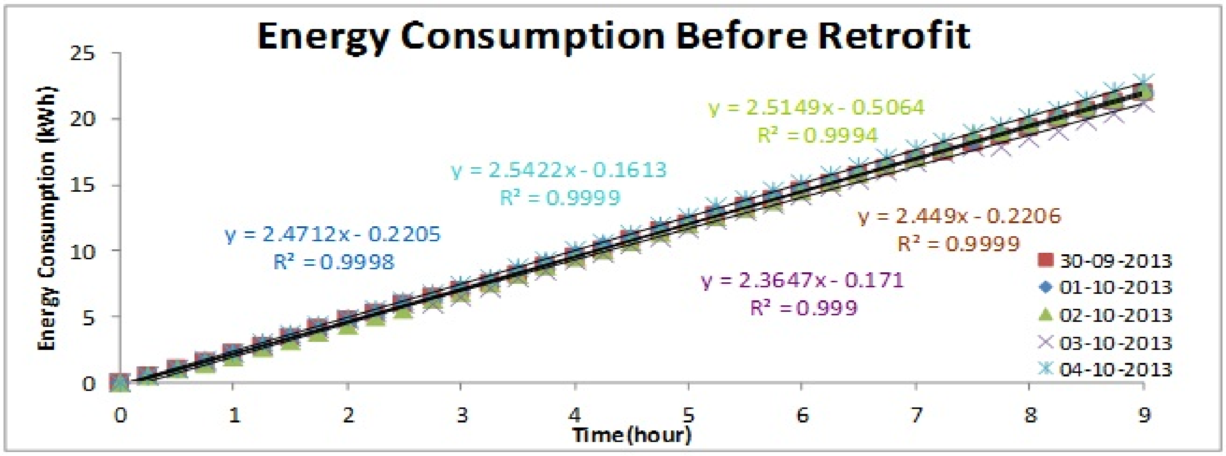

Figure-3. Energy consumption of air conditioner before retrofitting.

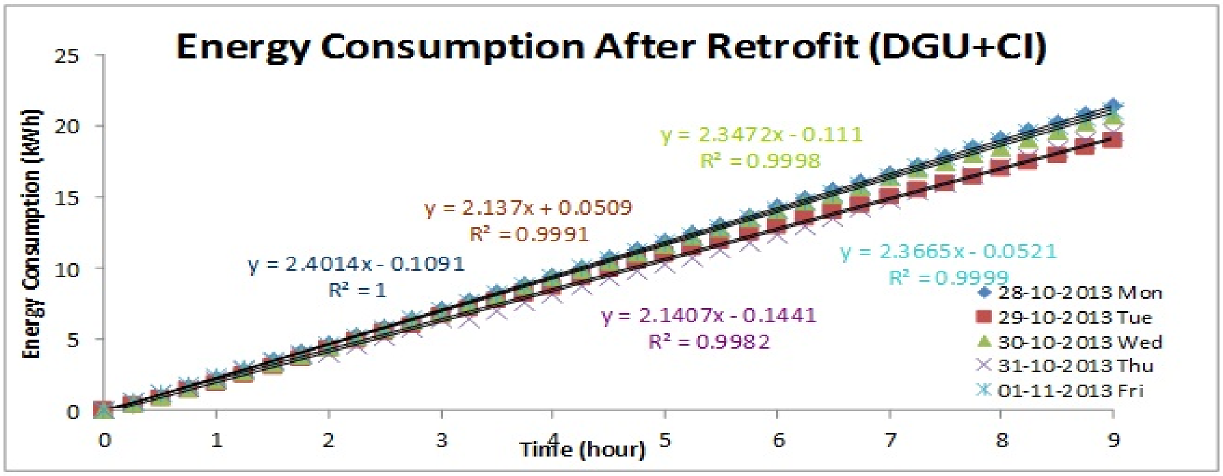

Figure-4. Energy consumption of air conditioner after retrofitting with DGU + CI.

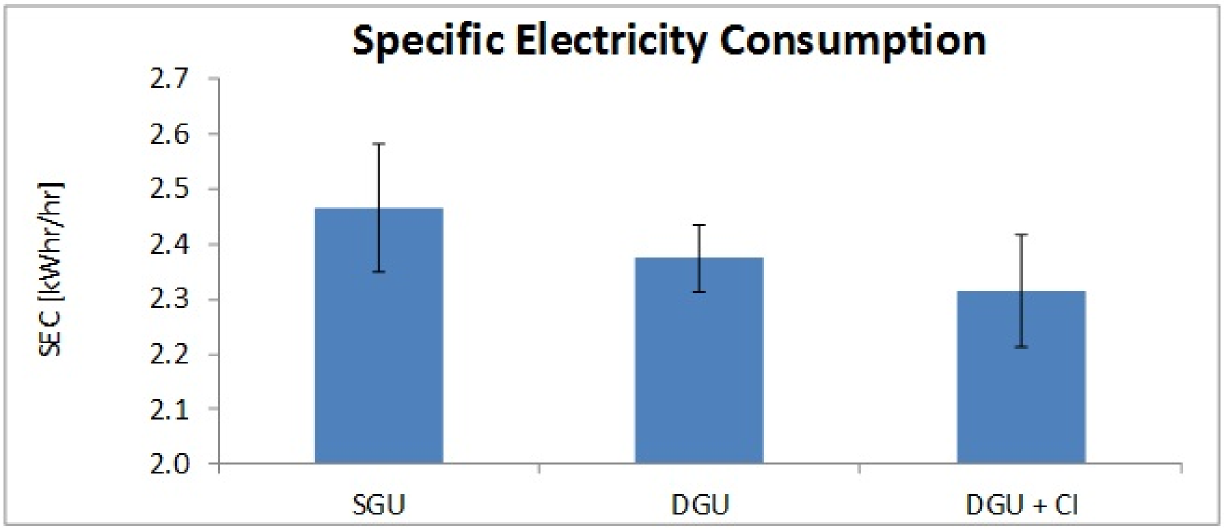

Figure-5. Specific electricity consumption of air conditioner before and after retrofitting internal lab with DGU and CI.

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Table-3. Specific electricity consumption of air conditioner in internal laboratory before (SGU) and after retrofitting (DGU + CI).

	SGU			DGU + CI		
	Weather	SEC [kWhr / hr]	R^2	Weather	SEC [kWhr / hr]	R^2
Monday	Sunny	2.44	0.9994	Sunny	2.40	1.0000
Tuesday	Sunny	2.47	0.9998	Sunny	2.32	0.9991
Wednesday	Sunny	2.52	0.9994	Sunny/Cloudy	2.35	0.9998
Thursday	Cloudy	2.36	0.9990	Cloudy	2.14	0.9982
Friday	Sunny	2.54	0.9999	Sunny	2.37	0.9990
Average		2.47 ± 0.12			2.31 ± 0.10	

Table-4. Average room temperatures for internal and external lab using two different data loggers and locations.

	HOBO Data Logger					LASCAR Data Logger	
	SGU	**DGU**	**DGU+CI**		**SGU**	**DGU**	**DGU+CI**
$T_{inner\ lab}$ [°C]	25.0	21.7	20.8		22.2	20.9	20.2
$T_{outer\ lab}$ [°C]	29.1	29.7	29.5		30.5	29.7	30.2
ΔT [°C]	**4.1**	**8.0**	**8.6**		**8.3**	**8.8**	**10.0**

From Figure-5 and Table-3 a decrease in SEC of up to 6.5 % can be observed after retrofitting the laboratory with DGU and CI. The average daily temperatures of the internal and external lab by using two different type of data logger were calculated and summarised in table 4. The air conditioner temperature was set to 16 °C before the retrofitting (SGU) and to 22 °C after installing the DGU. The external lab temperature remained resonably constant at 29.4 ± 0.3 °C suggesting comparable ambient conditions before and after retroftting. As shown in Table 3 the air conditioner was not able to achieve the set temperature of 16 °C arguably due to excessive heat transfer through SGU and window panels. After retrofitting, however, the temperature of the inner lab decreased from 25 °C to 20-22 °C for both data loggers demonstrating the effectiveness of DGU and CI. If the temperature set point of the air conditioner would be increased to 25 °C a further decrease in SEC can be expected as reported by Saidur who stated that for every degree Celsius increase the electricity consumption decreases by 6 % (Saidur, 2008). For HOBO data logger the temperature different of SGU to DGU+CI for the inner lab is 4.2 °C, while the LASCAR data logger is 2°C. The different value might resulting from the different location of the data logger placed.

It should be noted that the SEC of the air conditioner is also influenced by weather and internal heat gain from occupants, lighting and electrical equipment (Anonymous, 2009). From the data taken shows that the room will get colder when comes to the rainy days and the air conditioner will consume more electricity in the hot and sunny days working against a higher temperature difference. The influence of internal heat gain from lighting and equipment is assumed to be negligible because of similar usage pattern before and after retrofitting. However, the number of occupants and behaviour, which was not controlled in this experiment, may have contributed to different air change rates before and after retrofitting due to the opening and closing of the door. The number of internal lab users and duration of stay was not recorded. According to ASHRAE 2009 (Aun, 2009), occupants in air conditioned space release heat as a function of their metabolic rate, age, gender, weight and physical activities.

In order to obtain a more general value in SEC savings monitoring before and after retrofitting should be conducted over a longer period of time during which those external factors are expected to be more comparable. The cost of electricity can reduce to 3.75% per year after retrofitting, with ROI estimated approximately 12 years' time.

CONCLUSIONS

Retrofitting the air conditioned internal lab 16 at UniKL MICET with DGU and CI resulted in an SEC and temperature reduction of about 6.5 % and 2-4°C, respectively. The cost saving per year for electricity consumption is about 3.75%. This proved the theoretical prediction that the use of insulation for the building can decrease the heat transfer from hot environment into air conditioned space. Replication of the experiment over a longer time frame to eliminate the influence of external factors such as weather and internal heat gain is recommended. The room with occupied and unoccupied should be monitor too.

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