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A Comprehensive Case Study of Climate Change Impacts on the Cooling Load in an Air-Conditioned Office Building in Malaysia

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Abstract

In an earlier paper [1], the authors had comprehensively reviewed the climate change impacts for commercial buildings and their technical services in the tropics, and it revealed that numerous studies have been conducted to assess the climate change impacts in terms of energy consumption of a building. However, only few studies were carried out in the tropical region. This study aims to project the future cooling load needed for the years of 2000, 2020, 2050 and 2080 in the tropics using the TRNSYS simulation. Based on the simulation results, the total cooling load increases as the temperature changes. The total maximum cooling loads required in the years of 2000, 2020, 2050 and 2080 are 297000 kJ/hr, 305000 kJ/hr, 321000 kJ/hr and 332000 kJ/hr, respectively. When compared with the year 2000, the maximum cooling load needed in the years of 2020, 2050 and 2080 increases by 2.96%, 8.08% and 11.7% respectively. Based on the simulation results, in the next 70 years, the efficiency and durability of the existing system is predicted to decrease.

Keywords: Climate change impacts; Cooling load; TRNSYS; ACMV; Office building; Malaysia

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1. Introduction

A literature review by Yau and Hasbi [1] on climate change effects for large buildings and their technical services in the tropics was conducted. This review emphases on the buildings' contributions towards climate change and climate change effects on building structures, variations of energy consumption and peak demands, building load requirements, thermal comfort and emissions effects. In overall, buildings in regions with an estimated increase in temperature will require more cooling and less heating duties. Thus, building energy use and carbon emissions are anticipated to increase in its lifespan. In addition, the unpredictable weather trends will also affect the building effectiveness and sustainability, indoor air quality and thermal comfort. Even though the existing literature on this issue has increased substantially in recent years, there is still a need for further research in tropical climates as the climate change impacts vary with the different seasons, periods and regions.

The Fourth Assessment Report of the IPCC (AR4) predicted that building related carbon emissions to be around 8.6 million metric tons eqv in 2004 [2]. Note that Carbon emissions by definition is the carbon dioxide produced directly or indirectly caused by an activity. The major source of these emissions comes from combustion of fossil fuels for cooling, heating, lighting, and to power electrical appliances [3; 4]. Apart from this, the building industry is also responsible for a significant non- greenhouse gas emissions such as halocarbons, CFCs and HCFCs and hydrofluorocarbons (HFCs) due to their uses for cooling, refrigeration, and in the case of halocarbons, the insulation materials [2].

However, literature review reveals that research conducted on the investigation of the climate change impacts on the air-conditioning and mechanical ventilation (ACMV) systems in the office building in the tropics in terms of cooling loads is virtually none. For this purpose, the research must be conducted, and the aim is to examine the climate change impacts on the ACMV systems in the office building in the tropics in terms of cooling loads. For the present study, a small air-conditioned office in the Construction Research Institute of Malaysia (CREAM) building located in Kuala Lumpur, Malaysia, has been selected as a case study.

Nomenclature

ACMV	Air-Conditioning and Mechanical Ventilation
AR4	The Fourth Assessment Report of the IPCC
CLTD/CLF	Cooling Load Temperature Difference/Cooling Load Factor
CO2	Carbon dioxide
CREAM	Construction Research Institute of Malaysia
EMS	Energy Management System
HVAC&R	Heating, Ventilation, Air Conditioning and Refrigeration
IPCC	Intergovernmental Panel on Climate Change
SERG	Sustainable Energy Research Group
TMY2	Typical Meteorological Year
TRNSYS	Transient Systems Simulation Programme

2. Theory relevant to the current research

The climatic data details in the tropics will be described first in sub-section 2.1. The building descriptions will be discussed later in sub-section 2.2. The cooling load calculation and the weather profile due to the temperature change will be illustrated in sub-sections 2.3 and 2.4, respectively.

2.1. Climatic data

Kuala Lumpur, the capital of Malaysia is located in longitude 2°30' N and longitude 112°30' E with the total area of 329, 750 sq km. Malaysia's climate is categorised under the Koppen Climate Classification scheme as AF, Tropical Wet climate with some small areas of highland climates. The monsoon season sets in yearly from October to February in the Northwest and from April to October, in the Southwest. The climate characteristics such as temperature, relative humidity and solar radiation are uniform throughout the year with no large variations. The average mean temperature ranges from 24.6 to 31.6˚C and the mean relative humidity ranges from 76 to 82 %. As a hot-humid tropical climate country, Malaysia receives an annual total radiation of 7-10 hour of sunshine per day, and thus, increasing the indoor temperature, which normally requires the use of air conditioners to keep the occupants' comfort thermally satisfied.

2.2. Building descriptions

The CREAM building is located in Kuala Lumpur. The building's location and Malaysia's climatic conditions can be explained by the heat island effects experienced by the building. The building consists of two floors; where the ground floor houses the laboratories and the first floor is mainly offices where the current study took place. The office space chosen for this case study is facing north with double- glazed windows. The office accommodates almost 20 occupants at a time and operates for nine hours per day (9.00am to 5.00 pm), five days per week (Monday to Friday). The floor area is 324m² with 2.5 m height.

2.3. Cooling load calculation

The cooling load calculation is commonly used to predict the building's cooling capacity. The orientation of the building, physical dimension and ceiling height, material properties of the wall and window, number of people, computer, and lighting are included in the calculation. As the building does not have its own building energy management system (EMS), the Cooling Load Temperature Difference/Cooling Load Factor (CLTD/CLF) is applied to estimate the building's cooling load.

The calculated cooling load of the office space is 186,000 kJ/hr and the cooling capacity of the air-conditioning installed in the office space is 211,000 kJ/hr. Based on the results obtained from the calculation, the estimated cooling load needed is smaller than the cooling capacity. This implies that there is an over-sizing factor by 1.34, which has been applied to the estimation of cooling load during the installation. An oversized air conditioner contributes to the occupant's discomfort and higher initial and operating costs. The oversized air conditioner in the office space has also greatly reduced the moisture in the office. In turn, a low moisture level in the space makes the occupants feel dry. The low relative humidity causes the occupants feel the temperature is lower than it is. Even though the temperature is within the acceptable range, the occupants tend to wear extra clothing during working hours as they feel cold, even when the temperature is within 24-28˚C, based on the observation during the building walk-through. In addition, the excessive air-conditioning makes the space feel damp and stuffy.

Traditionally, the over-sizing factor is applied to the cooling load calculation to ensure that the air-conditioning system is able to provide cooling more quickly and avoids any chance of not meeting the cooling demand. To deliver the cooling more quickly, the oversized air conditioner runs at a shorter time, and requires extra energy, which creates added demand to the electrical generation and delivery system. The short run-time does not allow the system to remove humidity effectively, which affects the occupant's comfort and system's durability. On the other hand, a long run time will affect the system's life span. Therefore, as the optimum efficiency is accomplished at continuous running, the properly-sized air conditioner should run accordingly to be able to cool the space efficiently. In the future, the oversized air conditioners will contribute to the increase in the greenhouse gas emissions, in which, it increases the climate change impacts on us in the end.

2.4. Weather data profile - The temperature change

For the purpose of simulation, the Typical Meteorological Year (TMY2) weather data files for different years in Kuala Lumpur, Malaysia have been created by Sustainable Energy Research Group (SERG) in the UK in collaboration with the Heating, Ventilation, Air Conditioning and Refrigeration (HVAC&R) Laboratory, University of Malaya [5].

3. TRNSYS simulation

The cooling capacity of an air conditioner depends on the outdoor and indoor conditions. Related to this, the impacts of climate change, for instance, the increase in temperature will definitely affect the cooling load demand in the space. The sustainability and durability of the installed system is forecasted using the TRNSYS simulation.

The baseline simulation was developed using the TRNSYS Simulation Studio based on the design specification obtained and the site study at the building. Essentially, this simulation requires several settings for certain modules. In this case, the building has been modeled in the multi-zone module (Type 56a) as shown in Figure 1. The space geometry, orientation of the building, the portion of the window in percentage, material properties of window, wall and roof, heat gain due to occupants, laptop and lighting is defined in Type 56a. In this case, only the north and west sides of the office are facing the sun. The building materials used, theirs U-values and sources of heat gains were described in Tables 1 and 2.

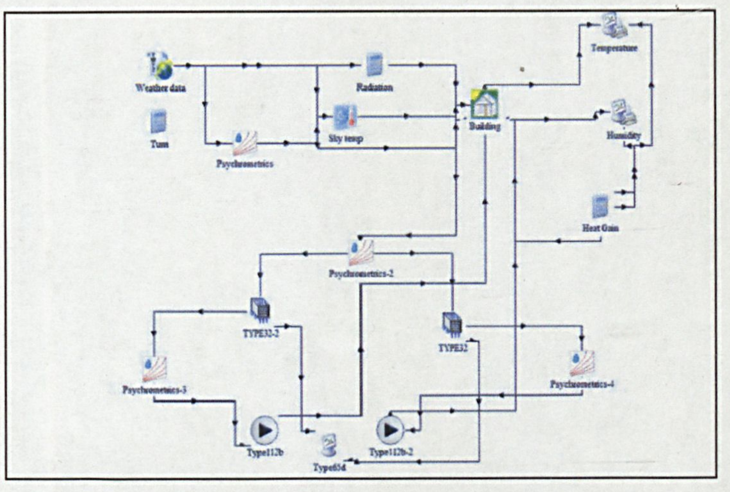

Fig. 1. TRNSYS Baseline simulation.

Table 1. Building materials.

Building Construction	Details	U-value (W/m²K)
Wall	Plaster (0.03m) Brick (0.115m) Plaster (0.03m)	2.256
Roof	Concrete (0.24m), Insulation (0.16m)	0.233
Internal Floor	Floor (0.005), Stone (0.06m), Silence(0.04m), Concrete (0.24m)	0.834
Window	Double glazing, (height:1.219m, width 0.914m)	1.4

Table 2. Heat gain sources.

Details	Quantity
Occupants	15
Laptop	15
Lighting Fluorescent	120

The equivalent air-conditioning system for the space is developed and then integrated through the ventilation with inlet air properties settings inside the multi-zone module (Type 56a). The cooling load rate, dry bulb temperature and relative humidity are plotted using the output plotter module (Type 65b). From the baseline model, the maximum cooling load required by the office space is determined by using the TRNSYS Studio with four different years of the TMY2 weather profile data in Kuala Lumpur, Malaysia.

4. Results and Discussion

It is observed that from the simulation results, as indicated in Figure 2, that the total cooling load increases with the years. The total maximum cooling load required in the years of 2000, 2020, 2050 and 2080 are 297,000 kJ/hr, 305,000 kJ/hr, 321,000 kJ/hr and 332,000 kJ/hr, respectively. When compared with the year 2000, the maximum cooling load needed in the years of 2020, 2050 and 2080 increases by 2.96%, 8.08% and 11.7% respectively. The result has strongly indicated that there is a significant impact of climate change on the maximum cooling load on building ACMV systems in the future in the tropics, especially in Malaysia.

The increment of the cooling load for the next 70 years is due to the increase of the outdoor temperature, which increases the amount of heat transfer from outdoor to the indoor space through the building's wall, window and roof. It can be seen that the solar radiation and its heating effects have the most significant influence on the energy needs in the tropics. The increase in temperature as well as the solar radiation will increase the conduction and radiation heat gain into the office space. In this case study, the additional cooling load is required to remove heat from the building as the outdoor temperature continues to increase.

By referring to the simulation results, it can be seen that the climate change effects in the tropics in terms of temperature change have significantly affected the cooling load required by the building. As the design cooling load is 211011 kJ/hr (as shown in Figure 10), the system will not be able to provide sufficient cooling load to the office space in the future as the maximum cooling load needed in the year 2080 is 332000 kJ/hr as indicated in Table 3. The incapability of the existing system to meet the cooling load requirement shown in Figure 2 will lead to overheating in the office space. The overheating condition affects the occupant's health and thermal comfort. The increase in the outdoor temperature will exacerbate the situation even further.

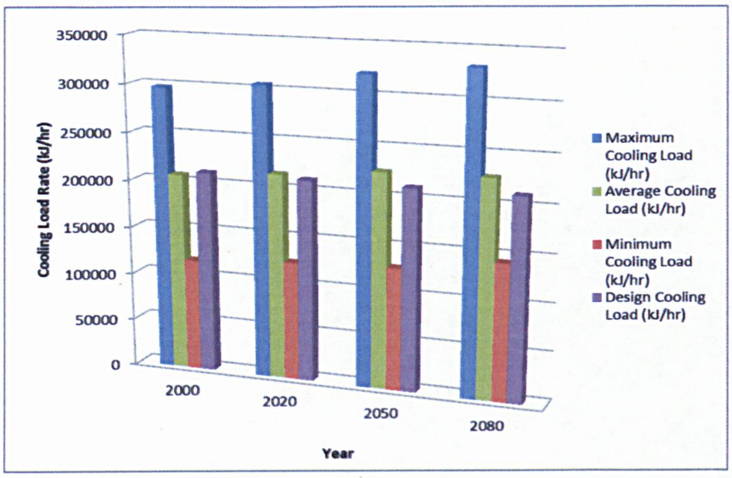

Fig. 2 Projected Cooling Loads in Years 2020, 2050 and 2080.

Table 3. Maximum cooling load for years 2000, 2020, 2050 and 2080.

Year	Maximum Cooling Load (kJ/hr)	Minimum Cooling Load (kJ/hr)	Average Cooling Load (kJ/hr)
2000	297 ,000	117 ,000	207,000
2020	305 ,000	124 ,000	215,000
2050	321 ,000	128 ,000	225,000
2080	332 ,000	143 ,000	227,000

5. Conclusions

The present research in the investigation of the cli-mate-change impacts on the ACMV systems in the office building in Malaysia in terms of cooling loads has been successfully conducted. The results can serve as an important guide to building services engineers for designing an efficient ACMV system for the future in the tropics.

The sustainability of the air-conditioning system installed in the building refers to whether the system can provide sufficient cooling capacity in the future with estimated climate-change whilst maintaining its efficiency and performance of the overall system. The sustainability of the air-conditioning depends on its power consumption and carbon emission. Based on the simulation result, the efficiency and durability of the existing system are predicted to decrease in the next 70 years.

Temperature is one of the crucial weather variables that affects the system performance. Findings from this study strongly imply that the temperature change has significant effects on the cooling load needed by the office space, and hence, increasing the risk of overheating. As the comfort and energy always oppose each other, the increased use in energy is expected to keep the space thermally comfortable for the occupants with the increase in the outdoor as well as indoor temperatures. In the future, existing buildings need to have adaptive plans to manage the overheating condition in the office space.

Regular maintenance of the existing system is necessary to ensure that the system functions effectively and efficiently throughout its year of service. As buildings last for decades, the existing system needs to be retrofitted to ensure that the system will be able to provide sufficient cooling required by the space without compromising the occupant's comfort. The office space can be converted into a low-energy office by reducing its heat gain. Implementation of the external shading devices, increasing the insulation in the walls and roof and replacing the single glazing with double glazing are some of the actions that can be taken to ensure that the building will adapt to the current changes in the climate.

In short, the current study represents the climate-change effects in terms of the cooling load required by existing buildings in the future. Findings from the present study can be used in choosing suitable ACMV systems in the future buildings as it aims to bridge the current and future building designs. It is hoped that the present study can translate complex issues regarding building design and climate change into an approach that is potentially useful for building designers in the future. The current research is undertaken to initiate the environmental awareness among the building designers.

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