INVESTIGATION ON PARAMETER INFLUENCING THE EFFICIENCY OF PASSIVE COOLING OF A TWIN BUILDING

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INVESTIGATION ON PARAMETER INFLUECING THE EFFICIENCY OF PASSIVE COOLING OF A TWIN BUILDING

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A dissertation submitted in partial fulfilment
of the requirement for the degree of
Bachelor of Engineering with Honours
(Chemical Engineering)

Faculty of Engineering
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Dedicated to my beloved parents and supervisor who always provide me with unconditional encouragements, motivations and supports

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ABSTRACT

Passive cooling techniques are the approaches with can replace the conventional cooling method to provide space cooling for a building with low or no energy consumption. Conventional cooling method requires high energy consumption and at the same time releases tremendous amount of greenhouse gases that can cause environmental problems. Heat dissipation and modulation technique, such as wind driven ventilation, buoyancy driven ventilation, evaporative cooling, ground cooling and evaporative cooling, are example of passive cooling techniques. Nevertheless, compare to passive cooling using insulation, these types of passive cooling are relatively more dependent on the environment condition, such as wind speed, climate or other characteristics like construction materials, available equipment and others. Aerogel is an advance artificial material, which has high potential as insulator as it can inhibit heat conduction and convention. This research will study about the potential passive cooling technique using aerogel insulation in tropical region under Malaysian conditions by studying few suitable parameters. Details or suitable methodology has been defined to have a good outcome of the research. The effectiveness of the aerogel to reduce the indoor temperature of the student had been study through the EnergyPlus^{TM} simulation. From the temperature profile generated, aerogel insulation is able to reduced up to 4.376℃. Besides, study on the effect of ventilation rate of a building in providing the passive cooling also been done. From the result, it shown that the temperature of the building decrease as the ventilation rate increase. Nevertheless, the aerogel insulation is not recommended to be too thick as most of the insulated heat load is been done on the first later of the aerogel insulation. Increasing in insulation can further decrease the temperature but it does not show a significance different. Challenges of the application of the aerogel insulation is mainly on the cost of the aerogel at with the calculated simple payback period up to 14 years. The simulation result is validated by comparing the simulation result with the actual experimental result which shows the maximum and minimum deviation of 8.75% and 0.49% respectively.

***Keywords**: Passive cooling techniques, Heat dissipation and modulation technique, Aerogel insulation, Ventilation rate, EnergyPlusTM simulation,*

ABSTRAK

Teknik penyejukan pasif adalah pendekatan yang boleh menggantikan kaedah penyejukan konvensional untuk menyediakan penyejukan ruang untuk bangunan dengan penggunaan tenaga yang rendah atau tiada. Kaedah penyejukan konvensional memerlukan penggunaan tenaga yang tinggi dan pada masa yang sama membebaskan sejumlah besar gas rumah hijau yang boleh menyebabkan masalah alam sekitar. Teknik pelesapan dan modulasi haba, seperti pengudaraan dipacu angin, pengudaraan didorong keapungan, penyejatan penyejatan, penyejukan tanah dan penyejatan penyejatan, adalah contoh teknik penyejukan pasif. Namun begitu, berbanding dengan penyejukan pasif menggunakan penebat, jenis penyejukan pasif ini secara relatifnya lebih bergantung kepada keadaan persekitaran, seperti kelajuan angin, iklim atau ciri-ciri lain seperti bahan binaan, peralatan yang ada dan lain-lain. Airgel ialah bahan buatan awal, yang mempunyai potensi tinggi sebagai penebat kerana ia boleh menghalang pengaliran dan konvensyen haba. Penyelidikan ini akan mengkaji tentang potensi teknik penyejukan pasif menggunakan penebat airgel di kawasan tropika dalam keadaan Malaysia dengan mengkaji beberapa parameter yang sesuai. Perincian atau metodologi yang sesuai telah ditakrifkan untuk mempunyai hasil penyelidikan yang baik. Keberkesanan aerogel untuk mengurangkan suhu dalaman pelajar telah dikaji melalui simulasi EnergyPlusTM. Daripada profil suhu yang dihasilkan, penebat airgel mampu dikurangkan sehingga 4.376 ℃. Selain itu, kajian tentang kesan kadar pengudaraan sesebuah bangunan dalam menyediakan penyejukan pasif juga telah dilakukan. Daripada keputusan tersebut, ia menunjukkan bahawa suhu bangunan berkurangan apabila kadar pengudaraan meningkat. Namun begitu, penebat aerogel tidak disyorkan untuk menjadi terlalu tebal kerana kebanyakan beban haba terlindung dilakukan pada penebat aerogel yang pertama kemudian. Peningkatan dalam penebat boleh mengurangkan lagi suhu tetapi ia tidak menunjukkan perbezaan yang signifikan. Cabaran penggunaan penebat aerogel adalah terutamanya pada kos aerogel pada dengan tempoh bayaran balik mudah yang dikira sehingga 14 tahun. Keputusan simulasi disahkan dengan membandingkan hasil simulasi dengan keputusan eksperimen sebenar yang menunjukkan sisihan maksimum dan minimum masing-masing 8.75% dan 0.49%.

***Kata kunci**: Teknik penyejukan pasif, Teknik pelesapan dan modulasi haba, Penebat Airgel, Kadar pengudaraan, simulasi EnergyPlusTM,*

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ABBREVIATIONS

AC	Air Conditioning
CFC	Chlorofluorocarbon
CTF	Conduction Transfer Function
EPS	Expanded Polystyrene
HCFC	Hydro Chlorofluorocarbons
ICB	Expanded Cork Agglomerate
LWA	Expanded Clay Lightweight Aggregates
NIR	Near Infrared Reflectance
PASB	Polyethylene Aluminium Single Bubble
PCM	Phase Change Materials
PUR	Polyurethane
UV	Ultraviolet
WFW	Woven Fabric Waste
XPS	Extruded Polystyrene

NOMENCLATURE

%	Percent
”	Inches
°	Degree
$°E$	Longitude
$°N$	Latitude
Al	Aluminium
℃	Degree Celsius
cm	Centimetres
CO_2	Carbon Dioxide
GT	Giga Tonnes
m	Metres
m/s	Metre Per Second
mm	Millimetres
PO_4^{3-}	Phosphate Ion
RM	Ringgit Malaysia
$Y_2Ce_{2-x}Tb_xO^7$	Terbium-Doped Yttrium Cerate
W/m℃	Watt Per Metres Degree Celsius
W/mK	Watt Per Metres Degree Kelvin
μm	Micrometres

CHAPTER 1

INTRODUCTION

1.1 Background

The consumption of energy is becoming a concerned issue starting this century. The use of energy is always interrelated with the effect to the environment, especially for the countries that generate the energy from carbon-based sources, such as fossil fuels, coal, petroleum and others non-renewable energy sources. A lethal impact to the environment caused by extreme used of energy is the release of carbon dioxide (Shaari et al., 2020), which might cause several environmental problems, such as greenhouse effect and global warming. Environmental issues are important topics since the last few decades, which can be proven by the implementation of several international protocols participated by more than hundred countries in the world, such as the Kyoto Protocol which was created in year 1997 as a response to the issue of greenhouse gasses emission that causes global warming, and Montreal Protocol that was established in year 1987 to mitigate the issue of ozone depletion.

Based on the World Watch Institute data, 40% of the world's energy is consumed by the building annually (Yüksek & Karadayi, 2017). According to International Energy Agency, IEA (2020), the energy needed for space cooling has been increasing triply since year 1990 and was blameworthy for around 1GT of CO_2, which consumed around 8.5% of the total electricity in the year 2019. Same statement can be supported with the data from the report published by the Global Alliance for Building and Construction which is "The 2019 Global Status Report for Building and Construction". From the report, it has shown that the final energy consumption of the space cooling for the building is the highest from year 2010 to 2018 as shown in **Figure 1.1**. Meanwhile, the energy intensity of the space cooling showed a trend to increase from 2014 until 2018 as shown in **Figure 1.2** and are expected to increase in the coming years. All the data had shown the impact of space cooling with the purpose of bringing comfort to the resident or the vacant of the building that had consumed a lot of energy. This had directly caused the problems that had been mentioned due to over energy consumption.

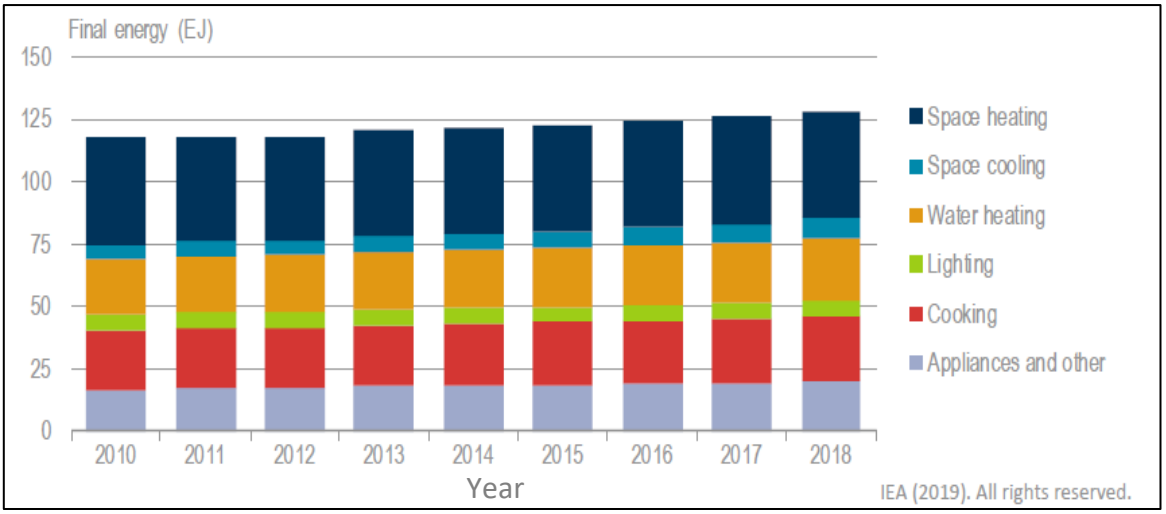

Figure 1.1. Global building sector final energy consumption by end use for year 2010-2018 (IEA, 2019).

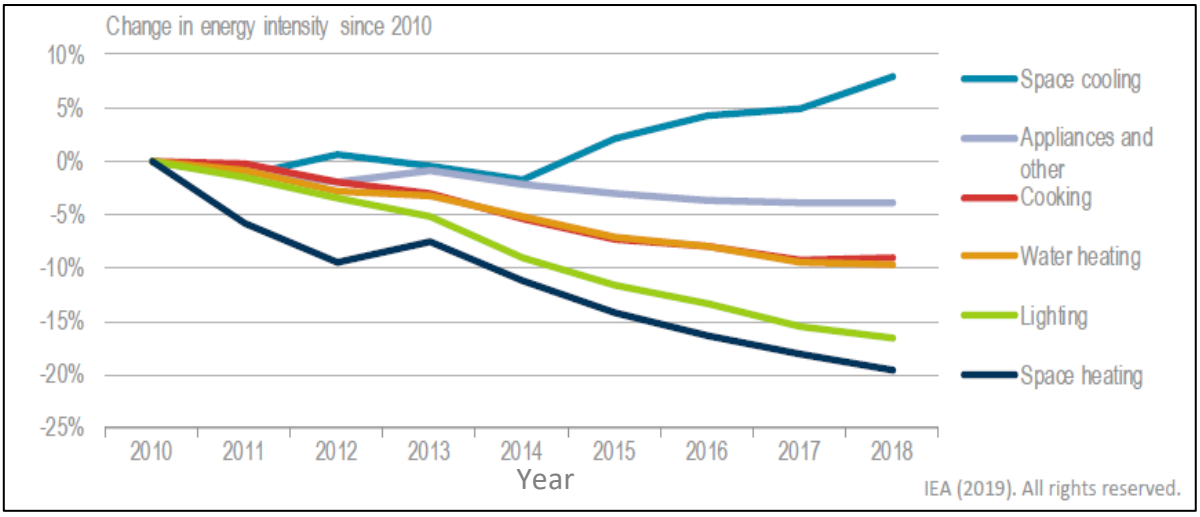

Figure 1.2. Global building sector final energy intensity changers from year 2010-2018 (IEA, 2019).

Hence, the application of the concept of energy efficiency and advance technology is important to solve this issue. Instead of using conventional cooling or refrigeration methods, such as air conditioning (AC), which brings negative consequences, such as release of chlorofluorocarbon (CFC) that might cause depletion of ozone layer, several other cooling techniques can be used. A variety of research had found out that, the use of passive cooling technique is an effective and direct way to reduce the energy consumption of a building, which results in a high efficiency energy use besides maintaining energy conservation(Adebisi et al., 2018; A. A. Chowdhury et al., 2016; Desai et al., 2019).

Passive cooling technique is a method which can provide thermal comfort to the resident or occupant of the buildings by removing the heat from the building or dissipating the heat from entering the building with no or low energy usage. The cooling can be achieved through the application of knowledge of natural phenomena, building design, materials construction or even utilization of the energy from the environment, such as wind or solar energy. In fact, the passive cooling technique is not a modern developing technique but had been implemented in early of the time. Some examples of the earlier application of passive cooling technique are the wind tower (Dehghani-sanij et al., 2015), and water mist spraying (Ulpiani, 2019), which have a history of more than 40 years.

There are many different methods that have been discovered and improved to make the passive cooling technique more efficient and has higher potential to be implemented. Several techniques have been studied, including the design of the building (Chu & Chiang, 2014; Mumovic & Santamouris, 2018), roof insulation (Pisello et al., 2016; Raj et al., 2015), subground passive cooling system (Chok & Chan, 2017), wall insulation (Bashir & Leite, 2021a; Yang et al., 2019) and others different methods. The passive cooling technique using insulation can be said as an efficient method as it does not require much lifetime maintenance or cost. It only needs to be installed during the construction of the building. Besides, through the research and development by the researchers, the performance of insulation materials is increasing. For example, the using of phase change materials (PCM) as the insulation has shown good performance (Kumar et al., 2021). Besides, the studies and invention of the NIR reflective pigment to be used on the roof insulation has improved the NIR reflectivity and also the performance of the roof insulation (Cozza et al., 2015; Rosati et al., 2021). In short, the development and significance of passive cooling technique to the society or environment make it worthy to be studied.

Moreover, it is worth mentioned that some of the passive cooling techniques, which design the building to have maximum ventilation, are able to reduce the possibility for the transmission of Covid-19 virus in the building (Bhagat et al., 2020; Dietz et al., 2020; Spennemann, 2021).

1.2 Problem Statement

According to Sena et al. (2021), residential areas contribute around 20.7% of the energy consumption in Malaysia. In Malaysia, the energy used in the buildings for resident or tenants' comfort through air conditioning and refrigeration is more than 50% (Hassan et al., 2014). The

energy consumption for the cooling purpose of the building, houses and office in Malaysia is increasing as the time going. This condition is similar to most of the countries around the world. Energy consumption is always a concerned topic as it is related to many different aspects, such as energy efficiency or energy trilemma. The proper consumption of energy is important in order to save energy. For example, in term of energy efficiency, it is important to use less energy to perform the same job. Hence, passive cooling method is a potential method to replace the conventional cooling method. There are many available passive cooling methods which is the results of many researchers and scientists. Passive cooling method is able to produce cooling effect to the building without consume as much energy as the conventional cooling method. Hence, energy saving is achieved in this term.

Besides, the conventional cooling method, such as air conditioners, has caused environmental problems. Carbon dioxide or the thermal energy that is released due to the energy consumption causes greenhouse effect. Besides, chlorofluorocarbon (CFC), which is frequently used as a synthesis substance in the refrigeration cycle of the air conditioners, is released during the usage of the air conditioning system. CFC gas will cause ozone depletion which is another concerned environmental issue in 21st century. Passive cooling method usually uses the natural phenomena of the environment, materials which does not require energy, such as wall insulation or roof insulation, and solar energy, which consumes no energy or is environmentally friendly.

However, the implementation of passive cooling method in producing a cooling effect for the building is still limited. Studies that were carried out by current researchers still not sufficient to encourage the replacement of the conventional cooling method by the passive cooling method. Hence, this study will emphasis on one type of passive cooling method, which is cooling using insulation. Passive cooling method by insulation is considered as a simple and feasible method which does not involve advance technology or instrument. This study will focus on the effectiveness of the passive cooling method on the twin building that is built in tropical region to provide the society new knowledge about the ability to apply the method in a building.

1.3 Research Question

This project engrosses on the study of the passive cooling method using insulation in different air humidity condition for a twin building structure and the research questions are shown below:

i. How will the passive cooling method using different thicknesses of the insulation affect the internal temperature profile of the twin building?
ii. What is the effect of the ventilation rate of the building as a passive cooling method for the twin building in tropical condition?
iii. How does the simulation result vary from the environmental result and the possibility of implementing the passive cooling technique in the actual environment?

1.4 Objectives of the Study

The overall aim of the project is to study the effectiveness and the effect of using passive cooling method for a twin building structure in different air humidity condition. Precisely, this research project focuses on using the aerogel insulation as the passive cooling method for the building. To produce a good outcome of this research project, which can cover the analysis in different views or aspects, the following objectives had been organised:

i. To study the effect of passive cooling method using different thicknesses of the aerogel insulation to the internal temperature profile of a twin building structure.
ii. To study how the ventilation rate produce the cooling effect to the twin building by observing the temperature profile.
iii. To analyse and compare the simulation and experimental result and to verify the simulation by comparing with actual experiment works.

1.5 Scopes of the Study

This research project emphasises on the study of the passive cooling method using aerogel insulation. The effectiveness of the passive cooling method using different thicknesses of aerogel such as 10mm, 20mm, 30mm, 40mm and 50mm is studied. In this study, the passive cooling method using insulation is applied on the twin building that is built in the tropical condition. The effectiveness of the method is studied by analysing on the internal temperature profile of the twin building, in which the result is obtained through simulation using the energy simulation programme known as Energy Plus™. Besides, the effect of the ventilation rate of

the building to its temperature profile. To further prove the result obtained from the simulation is genuinely and logically acceptable, it is compared to the experimental result through the real twin building built in an organic farm at Serian, Sarawak. Finally, the discussion on the ability of the passive cooling method using insulation to be applied in the Malaysia building is studied and discussed at which brings benefits to the people, economy and environment.

1.6 Significance of the Study

Several significances based on the outcome resulted from this research project has been highlighted as shown below:

i. The detailed understanding of the effectiveness and benefits of passive cooling method using insulation in producing the cooling effect for a building can be gained.
ii. The result obtained from the simulation is able to determine the applicability of the ventilation system as a passive cooling method.
iii. The outcome of the finding is able to bring knowledge to the publicity about the importance and benefit of using the passive cooling method instead of the conventional cooling method that requires more energy and promote the passive cooling method among the society.

1.7 Summary

This chapter had explained the background of this project and the significance of this research to the society. As been mentioned, energy consumption problems and environmental problems might cause negative consequences to human being and even their future generations. As the energy usage of space cooling is high, it is important to use a greener, more energy efficient, environmentally friendly, harmless technique to produce the same cooling effect rather than using the conventional cooling method, such as air conditioning system. Without a doubt, passive cooling technique is an efficient alternative to replace the old school cooling method which requires highly energy consumption for space cooling. Few types of passive cooling technique had been introduced and it will be explained in detail in the next chapter. Passive cooling using aerogel as insulation will be emphasised in this research on its potential to be implemented in the buildings in tropical region. The effect of ventilation rate to the building temperature profile will also be investigated through the simulation using Energy

Plus™. Detailed methodology will be explained in the further chapter. For the verification of the simulation result, it will be compared with the experimental data obtained.