IMPACT OF BUILDING GEOMETRY FACTORS ON THERMAL COMFORT AND ENERGY PERFORMANCES OF GLASS FAÇADE HIGH-RISE OFFICE BUILDINGS IN HOT AND HUMID CLIMATE MALAYSIA

by

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Thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy

April 2022

ACKNOWLEDGEMENT

بسم الله الرحمن الرحيم

"In the name of God, Most Gracious, Most Merciful"

I would like to express my greatest appreciation to my supervisor, Assoc. Prof. Ts. Dr. Mohd Rodzi bin Ismail, for his generous guidance, advice, motivation, valuable comment, and discussion throughout this research. I would also like to thank my co-supervisor, Dr. Nurul Hashimah Ahamad Hassain Malim for her support, assistance, and advice on programming during my simulation study. My gratitude goes to the Universiti Tun Hussein Onn Malaysia (UTHM) and the Ministry of Higher Education Malaysia (MOHE) for financial support which made this work possible. My sincere appreciation also goes to the School of Housing, Building and Planning support staff, who directly or indirectly involved in the process of completing this thesis, for their generous assistance, support, contribution, useful views, and tips. Finally, I would like to express my deepest gratitude and special thanks to my beloved parents, family, and friends, for their continuing financial and moral supports, endless love, prayers, and encouragement throughout my studies.

Specially dedicated to my parents, Roslan Sharif & Jamilah Nekmat.

فإن مع العسر يسرا إن مع العسر يسرا

"So verily, with every hardship, there is relief.
Verily, with every hardship, there is ease."
Qur'an 94:5-6

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LIST OF SYMBOLS

ΔU	Change in internal energy in the system
A_{ext}	Building external surface area
A_{wall}	Area of wall
A_{win}	Area of window
C	Building compactness
C_{buil}	Compactness of studied building
C_{clo}	Heat losses by convection from the outer surface of a clothed body
clo	Clothing insulation
C_{ref}	Compactness of the reference building
E_d	Heat losses from human body are through skin diffusion
E_{re}	Heat losses due to latent respiration
E_{sw}	Heat losses by evaporation of sweat
f_{cl}	Clothing surface factor
H	Internal heat production in the human body
h_c	Coefficient of convection heat transfer
i	Integer
I_{cl}	Thermal insulation of clothing
K	Heat losses due to conduction through clothing
L	Heat losses due to dry respiration
M	Metabolic rate
n	Number of samples
p_a	Water vapor pressure
PMV	Predicted Mean Vote
PMV_{limit}	Comfort range calculated according to this International Standard

$PPD_{actualPMV}$	PPD corresponding to the actual PMV
$PPD_{PMVlimit}$	PPD corresponding to PMV_{limit}
p-value	Significant level of the correlation
Q	amount of energy added to the system
Q_{cd}	Heat from exterior walls and roof
Q_{cdf}	Heat from conduction from fenestration
Q_{eq}	Heat from equipment
Q_{inf})	Heat from air infiltration
Q_{int}	Heat from internal walls and door
Q_{lgt}	Heat from electrical lighting
Q_{ppl}	Heat from people
Q_{total}	load required to maintain the room air temperature
R	Heat losses due to radiation
R^2	Regression coefficient
RC	Building relative compactness
RH	Relative humidity
t_a	Air temperature
T_c	Thermal comfort temperature
t_{cl}	Surface clothing temperature
$t_{dma(out)}$	Mean daily outdoor air temperature
T_m	Mean monthly outdoor temperature
t_{op}	Operative temperature
$t_{pma(out)}$	Prevailing mean outdoor temperature
t_r	Mean radiant temperature
V	Volume of building
v	Air velocity
w	Effective work

W	Correlation coefficient of Shapiro-Wilk normality test
α	Exponent for building terrain
β	Solar altitude angle
δ	Thickness of boundary layer
ρ	Spearman correlation coefficient
φ	Solar azimuth angle

LIST OF ABBREVIATIONS

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BEI	Building Energy Intensity
BREEAM	Building Research Establishment Environmental Assessment Method
BS	British Standard
BSEEP	Building Sector Energy Efficiency Project
CASBEE	Comprehensive Assessment System for Built Environment Efficiency
CFD	Computational Fluid Dynamics
CIBSE	Chartered Institution of Building Services Engineers
DBT	Dry bulb temperature
GBI	Green Building Index
GreenPass	Green Performance Assessment System
GreenRE	Green Real Estate
HVAC	Heating, Refrigerating and Air-Conditioning
IDF	Intermediate Data Format
ISO	International Standard
IWEC	International Weather for Energy Calculation
KSU	Kansas State University
LC	Large cities weather data
LCCF	Low Carbon Cities Framework
LCNI	Large cities, no infiltration weather data
LEED	Leadership in Energy and Environmental Design
MS	Malaysian Standard
MyCREST	Malaysia Carbon Reduction and Environmental Sustainability Tool
MyHGI	My Green Highway Index

NREB	Non-residential existing building
NRNC	Non-residential new building
PHJKR	Penarafan Hijau by Jabatan Kerja Raya
PMV	Predicted Mean Vote
PPD	Predicted Percentage of Dissatisfied
SHGC	Solar heat gain coefficient
SUSDEX	Sustainability Index
TMY	Test Meteorological Year
TVIS	Solar visible transmittance
UHI	Urban Heat Island
WFR	Window to floor area ratio
WS	Weather station weather data
WSNI	Weather station, no infiltration weather data
WWR	Window-to -wall ratio

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IMPAK FAKTOR GEOMETRI BANGUNAN TERHADAP PRESTASI KESELESAAN TERMA DAN PRESTASI TENAGA DALAM BANGUNAN PEJABAT BERTINGKAT TINGGI DENGAN FASAD KACA DI IKLIM PANAS DAN LEMBAP MALAYSIA

ABSTRAK

Tanah yang terhad di dalam bandar telah menyebabkan peningkatan bangunan tinggi yang mengakibatkan perubahan morfologi dan iklim mikro. Selain itu, penggunaan fasad kaca penuh pada bangunan tinggi telah menjadi trend dan ianya boleh mempengaruhi tenaga bangunan dan keselesaan terma dalam iklim panas dan lembap. Oleh itu, kajian ini dilakukan bertujuan untuk menilai variasi prestasi pada ketinggian bangunan yang berbeza, kesan kedalaman bangunan dan kesan bentuk bangunan terhadap prestasi tenaga bangunan dan prestasi keselesaan terma jangka masa panjang. Model kes asas bangunan 20 tingkat dengan fasad kaca penuh disimulasikan menggunakan program EnergyPlus dan RStudio. Sebanyak 4 keadaan iklim mikro, 6 nisbah kedalaman bangunan, dan 8 bentuk bangunan dinilai dengan memanipulasi orientasi dan luas lantai bangunan. Hasil kajian menunjukkan bahawa terdapat pengurangan penggunaan tenaga bangunan setelah mempertimbangkan pengaruh iklim mikro di sepanjang ketinggian bangunan. Bangunan dalam (1:1) menunjukkan prestasi yang lebih baik daripada bangunan cetek (6:1). Bagi bentuk bangunan, bentuk bulat adalah yang paling cekap tenaga, manakala bentuk Y adalah yang paling kurang prestasi tenaga. Kesimpulannya, penggunaan fasad kaca penuh menunjukkan lebih banyak pengaruh pada prestasi keselesaan terma berdanding tenaga bangunan. Oleh itu, penggunaan fasad kaca penuh dalam iklim panas dan

lembap kurang digalakkan dan memerlukan pertimbangan geometri bangunan yang sesuai pada peringkat awal reka bentuk.

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ABSTRACT

Limited land in cities have caused an increase of high-rise buildings and caused changes in the morphology and microclimate. Besides, the application of full glass façade on high-rise buildings has become a trend and could influence the building energy and thermal comfort in hot and humid climate. Thus a study was conducted to evaluate the variations of performance at different building heights, the effect of building depth and building shape on building energy and long-term thermal comfort performances. A base case model of 20-storey high-rise building with a full glass façade was simulated using the EnergyPlus and RStudio programmes. A total of 4 microclimate conditions, 6 building depth ratios, and 8 building shapes were evaluated by manipulating the orientations and floor areas of the building. The results indicated that there is a reduction in the building energy use after considering the effect of microclimate along with the building height. The deep building (1:1) was found to perform better than the narrow building (6:1). For building shapes, circle shape is the most energy efficient shape, while Y-shape has the lowest energy performance. In conclusion, the application of a full glass façade shows more influence on the thermal comfort performance compared to building energy. Hence, the application of a full glass façade in the hot and humid climate is less favourable and requires consideration of appropriate building geometries at the early design stage.

CHAPTER 1

INTRODUCTION

1.1 Background

Globally, populations in rural areas are less than in urban areas. According to World Urbanization Prospect (2015), 70% of the people lived in rural areas, while 30% lived in urban areas in the year 1950. This percentage keeps increasing by up to 54% of the world's urban population in the year 2014 and expected to become more than 70% in the year 2050. Possible reasons behind this rapid urbanisation are economic growth and job opportunity offers in urban cities.

In order to accommodate the increasing populations, a drastic number of high-rise office or residential buildings have been developed to provide a better workplace and living environment. High rise buildings become a choice due to lack of land area. However, the increasing number of high-rise buildings in the cities could lead to urban heat island phenomena, hence contributes to global warming if the buildings are not properly designed.

Nowadays, sustainability becomes the main consideration in designing a building. Many indicators have been implemented in the construction of a sustainable building. The important approach in designing a sustainable building is by considering its energy consumption. Rubio-Bellido et al., (2016) stated that the current focus in building science research and development is to investigate the future energy consumption, which later forecasts the impact of future global climate.

In reducing the impact of global climate, many studies on energy consumption have been conducted with the aim of incorporating sustainability in building design and subsequently, various simulation researches have taken place in order to predict it. Numerous studies on optimum building geometry to reduce energy consumption have also been carried out as building geometries such as orientation, shape, window-to-wall ratio and glazing material play important roles in building design.

Equally important, the thermal comfort of the building occupants is one of the important factors in designing a sustainable building. Some might have overlooked this factor so as to reduce the energy consumption of the building. Sustainability of the design can be achieved by balancing these two factors (i.e. thermal comfort and energy consumption).

Fanger (1970) defined human thermal comfort as the adaptability of each individual person when exposed to an artificial climate. Likewise, thermal comfort is the expression of satisfaction of humans with the thermal environment (ASHRAE Standard 55, 2013). There are factors need to be considered in providing thermal comfort which includes the air temperature, relative humidity, velocity of air, human activity level and thermal resistance of clothing. The most important one is the temperature of the room as a human is very sensitive to temperature change.

A better indoor thermal environment can be achieved by the use of air-conditioning systems to cool the space, especially in hot and humid climate countries. Almost all office buildings in the tropical region use air-conditioning systems to enhance comfort to the occupants. A research done by Santamouris (2015) showed that energy consumption in the buildings sector is almost 40% of the world's energy consumption. From those figures, 50% of it comes from the energy consumed by air-conditioning systems in a standard building (Bastide et al., 2006).

The tightness of the building envelope is very important for air-conditioned buildings to prevent the infiltration of outdoor air indoors in order to optimise the

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