EFFECTS OF ENVELOPE COLOR AND HEAT INSULATION ON BUILDING THERMAL PERFORMANCE

IKMALZATUL BINTI ABDULLAH

A dissertation submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Environmental Engineering

School of Graduate Studies
Universiti Teknologi Malaysia

JANUARY 2013

PENGARUH WARNA LUARAN DAN PENEBAT HABA TERHADAP KEBERKESANAN TERMAL BANGUNAN

IKMALZATUL BINTI ABDULLAH

Laporan dikemukakan sebagai memenuhi
sebahagian daripada syarat penganugerahan
ijazah Sarjana Kejuruteraan Alam Sekitar

Sekolah Pengajian Siswazah
Universiti Teknologi Malaysia

JANUARY 2013

To my beloved family and friends

ACKNOWLEDGEMENT

Thanks to Allah Almighty, who has given me the opportunity and will to perform this Master project. I find myself helpless to find the words to express the kindness and mercy of Almighty Allah, the most gracious, the most merciful, who is the ultimate source of all good to his creations.

First and foremost, I would like to express my heartfelt gratitude to my supervisor, Dr. Mohd Fadhil Md Din, for his vital guidance, encouragement and support throughout the process of my studies and his great contribution to the completion of this report. Without his supervision, the report would not have been the same as presented here.

Next, I would like to thank Mr. Zaabar and Mrs. Halimah, for their technical help in fabricating the experiment model and using the instrumentation. I appreciate the useful advices and technical assistance that given to me during the experimental period.

I would like to extend my appreciation to my coursemates and peers for sharing their insights and opinions on the project. Besides, I am very thankful to my family members for their continuous support and motivation. Lastly, I would like to convey my appreciation and acknowledgement to any individuals who had directly or indirectly contributed in making this project a success.

ABSTRACT

Buildings are large consumers of energy in all countries. In regions with extreme climatic conditions, a substantial share of energy goes to heat or cool the buildings. This heating and air-conditioning load can be reduced through many means; notable among them is the proper design and selection of building envelope and its component. This study evaluates the impacts of envelope color and heat insulation on building thermal performance. Two sets of experiment were conducted in the month of June 2011. In the first experiment, different coating colors was studied, i.e. white, yellow, and brown for types of concrete wall. While, orange, green, and dark brown were applied for roofing tiles in a small-scale prototype. The ambient temperature, surface temperature, solar radiation, wind speed and relative humidity were measured for seven sunny days starting 9.00 am to 7.00 pm. The coating colors that exhibit the lowest surface temperature and heat flux were applied on the three small-scale building models to examine the minimum heat transfer rate into the building. In the second set of experiment, three simulated models were fabricated; no insulation (referral study) and the other two were applied at different location of roof and wall structure, respectively. The heat transfer was computed in order to determine the effectiveness of EPS Geofoam as heat insulator. The total heat reduction between wall insulated and roof insulated models were also compared in order to determine the best placement of thermal insulation in building component. The results showed that white concrete wall exhibits the lowest surface temperature and heat flux at peak hour which recorded at 35.4 °C and 105 W/m^2, respectively. On the other hand, the orange roof tile depicts the lowest surface temperature and heat flux at peak hour at 37.4 °C and 3461 W/m^2, respectively. In addition, the application of EPS Geofoam demonstrated a remarkable result in reducing the heat transfer into the building. It reduced the internal wall and roof surface temperature by up to 3.0°C and 2.8°C respectively. EPS Geofoam showed the best performance when placed in the roof structure where the total heat flux was reduced by up to 76 percent compared to the control (referral) condition.

ABSTRAK

Di semua negara, penggunaan tenaga dalam bangunan adalah tinggi. Di kawasan-kawasan yang beriklim melampau, sebahagian besar tenaga digunakan untuk memanaskan atau menyejukkan bangunan. Beban pamanasan dan penyejukan ini boleh dikurangkan melalui banyak cara, namun yang paling berkesan adalah melalui rekabentuk dan pemilihan luaran serta komponen bangunan yang sempurna. Kajian ini menilai pengaruh warna luaran dan penebat haba ke atas prestasi termal bangunan. Dua set eksperimen telah dijalankan pada bulan Jun 2011. Untuk eksperimen yang pertama, warna salutan yang berbeza iaitu putih, kuning dan coklat telah digunakan pada dinding konkrit serta warna oren, hijau dan coklat gelap pada jubin bumbung dalam prototaip berskala kecil. Suhu udara, suhu permukaan, radiasi solar, kelajuan angin dan kelembapan relatif telah diukur selama tujuh hari yang cerah bermula pukul 9.00 pagi hingga 7.00 malam. Warna salutan yang menghasilkan suhu permukaan dan fluks haba yang terendah kemudian diaplikasikan pada tiga model bangunan berskala kecil yang digunakan untuk objektif kajian yang kedua, supaya pemindahan haba ke dalam model bangunan dapat dikurangkan. Dalam set eksperimen yang kedua, tiga model bangunan telah dibina, satu dibina tanpa penebat haba (rujukan) dan dua yang lain telah ditebat pada lokasi yang berbeza iaitu masing-masing pada struktur bumbung dan dinding. Pemindahan haba telah dikira untuk menentukan keberkesanan EPS Geofoam sebagai penebat haba. Pengurangan jumlah haba antara dinding yang berpenebat dan bumbung yang berpenebat juga dibandingkan untuk menentukan penempatan terbaik penebat haba dalam komponen bangunan. Hasil kajian menunjukkan dinding konkrit putih menunjukkan suhu permukaan dan fluks haba terendah pada waktu puncak iaitu masing-masing sebanyak 35.4 °C dan 105 W/m^2. Untuk jubin bumbung berwarna oren, ia menunjukkan suhu permukaan dan fluks haba terendah pada waktu puncak iaitu masing-masing, 37.4 °C dan 3461 W/m^2. Di samping itu, penggunaan EPS Geofoam menunjukkan hasil yang luar biasa dalam mengurangkan pemindahan haba ke dalam bangunan. Ia mengurangkan suhu permukaan dinding dan bumbung dalaman sehingga 3.0°C dan 2.8°C masing-masing. EPS Geofoam menunjukkan prestasi terbaik apabila ditempatkan pada struktur bumbung di mana jumlah fluks haba telah dikurangkan sehingga 76 peratus berbanding rujukan.

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SYMBOL	QUANTITY	UNITY
$\acute{\varepsilon}$	Emissivity	
σ	Stefan-Bolltzmann coefficient (5.67 × 10–8)	$Wm^{-2}K^{-4}$
T_s	Surface temperature	°C or K
T_a	Ambient temperature	°C or K
S_r	Solar radiation	Wm^{-2}
RH	Relative humidity	%
E	Energy of radiation	W/m^2
T	Temperature	°C or K
A	Area of the surface material	m^2
q_{rad}	Heat of radiation	W or J/s
q_{conv}	Heat of convection	W or J/s
q_{cond}	Heat of conduction	W or J/s
K_{conv}	Convection heat transfer coefficient	$W/ m^2.K$
N_{GR}	Grashof Number	
L	Length in vertical planes	m
ρ	Density	kg/m^3
g	Acceleration of gravity (9.80665)	m/s^2
β	Volumetric coefficient of expansion of fluid $1/(T_{film}) = 1/(T_s+T_a)$	K

ΔT	|positive temperature different between the wall and bulk fluid|	K
μ	Viscosity	kg/m.s
N_{PR}	Prandtl Number	
C_p	Heat capacity	J/kg.K
k	Thermal conductivity	W/m.K
x	Thickness	m
T_o	Outside temperature	°C or K
T_i	Inside temperature	°C or K

LIST OF ABBREVIATIONS

UHI	-	Urban Heat Island
EPS	-	Expanded Polystyrene
UV	-	Ultraviolet
IR	-	Infrared
HVAC	-	Heating, Ventilation, and Air-Conditioning
VOCs	-	Volatile Organic compounds
PM	-	Particulate Matter
SO_2	-	Sulfur Dioxide
CO	-	Carbon Monoxide
NO_x	-	Nitrous Oxides
CO_2	-	Carbon Dioxide

CHAPTER I

INTRODUCTION

1.1 Background of the Study

Malaysia is experiencing rapid economic growth especially in the last 2 or 3 decades. Extensive land development in urban areas has completely altered the surface profile of our cities. Tall office buildings are complemented by high-rise condominiums, flats and an increasing number of elevated highways and rapid transit railways winding through them.

As cities grow, buildings and paved surfaces replace the natural landscape. Hard, inert surfaces absorb the sun's heat, causing their temperatures to steadily rise with increasing exposure. Dark colored surfaces like roofs, roads and parking lots absorb the most heat. In our tropical climate, road and car park surface temperatures can exceed 60°C in the mid-afternoon when air temperature is about 30°C. Large masses of tarmac, concrete and steel buildings absorb and store large amounts of heat, which in turn radiate into the surrounding air. As a result, temperatures in city areas can be 10°C or more above suburban green areas (Ahmad and Norlida, 2003). This bubble of heat is known as an Urban Heat Island (UHI).

Due to the environmental changes, attention has been drawn to thermal comfort by reducing the heat transfer to the building by using high reflectances surfaces and proper thermal insulation. The purpose of thermal insulation is to provide a continuous thermal barrier to minimize heat flow through the walls, ceiling and floor. Insulation serves to keep a building comfortable and reduce costs for heating and cooling. It is generally agreed that buildings with high reflectance surfaces can improve the indoor thermal environment effectively. Likewise, styrofoam is used as the insulation material to produce energy-efficient buildings. Styrofoam insulation is a less expensive and economic way to provide insulation to a building.

1.2 Problem Statement

Urbanization and industrialization improve our material lives and comfort; however, they also induce many problems to human beings, such as global warming, industrial waste, and air pollution. More people are vulnerable to urbanization problems as the ever increasing urban population, which was estimated as 48% or three billion, is expected to be five billion by 2030 (Rizwan *et al.*, 2007).

The continuously growing size of the urban environment and the careless development of buildings and open spaces have a major impact on the urban microclimate. The building’s energy behavior and performance are heavily influenced by the density of the building space. In general, the observed heat island effect is mainly influenced by urban design, namely the canyon radiative geometry, anthropogenic heat and the material's street physical properties (Doulos *et al*., 2004). The emitted infrared radiation from the various buildings and street surfaces impinges on the surroundings surfaces and is entrapped inside the canyon. Besides, the total amount of the absorbed solar radiation is increased due to multiple reflections between the buildings.

The anthropogenic heat also increases the intensity of the global climate change and heat island effect through the use of fuels from either mobile or stationary sources. Furthermore, the incident solar radiation and every available heat form can increase the storage of sensible heat in the city's structure during the daytime. The stored heat is released into the urban atmosphere during the night period. Therefore the total amount of the energy balance is increased and air temperatures become greater (Doulos *et al*., 2004).

The resulting higher temperature has the effect of increasing the demand for cooling energy in commercial and residential buildings. Increased demand for energy can cost consumers and municipalities thousands of additional dollars in air conditioning bills in order to maintain comfort levels. In addition, proportional to the high demand on cooling energy will increase electricity generation from the power plants leads to higher emissions of sulfur dioxide (SO_2), carbon monoxide (CO), nitrous oxides (NO_x), and suspended particulates, as well as carbon dioxide (CO_2), a greenhouse gas known to contribute to global warming and climate change. Furthermore, UHI often accelerate the formation of harmful smog, as ozone precursors such as NO_x and volatile organic compounds (VOCs) combine photochemically to produce ground level ozone (Akbari, 2005). This smog can damage the natural environment and jeopardizes human health.

Among the factors that contribute to the global climate change, the thermal properties of the materials used in the urban fabric play a very important role. The presence of dark colored surfaces, particularly roofs and pavements, absorb solar radiation during daytime and reradiate it as heat during the night and furthermore the replacement of natural soil and vegetation by the materials reduces the potential to decrease ambient temperature through evapotranspiration and shading (Kolokotroni *et al*., 2008).

Therefore the use of high albedo urban surfaces is an inexpensive measure that can reduce temperatures. Increasing the reflectance of surfaces can be achieved by using ‘‘cool’’ materials that are characterized by a high solar reflectance and high infrared emittance values. The use of cool materials in the urban environment contributes to lower surface temperatures that affect the thermal exchanges with the ambient.

Besides, the building envelope is one of the important design variables for effective energy conservation. Therefore, the use of styrofoam as insulation material in building components, such as roof and wall is important for both energy savings and reducing undesirable emissions from the burning of fossil fuels. Nowadays, thermal insulation is a major contributor and obvious practical and logical first step towards achieving energy efficiency especially in buildings located in sites with harsh climatic conditions such as Malaysia.

1.3 Objectives of the Study

1) To measure the effects of different coating colors on roof tile and concrete wall thermal behavior.

2) To investigate the effectiveness of EPS Geofoam as insulation material in roof and wall structures.

3) To determine the best placement of insulation within the building component.

1.4 Scope of the Study

This study was carried out at outdoor environment that is suitable to measure the ambient and surface temperature as well as the humidity. Different coating colors which are white, yellow, and brown were applied to concrete wall as well as orange, green, and dark brown to roofing tiles in a small-scale prototype. These prototypes were placed on the parking lot at UTM Skudai. The difference in the surface temperature and heat flux was measured. The coating color that gives the lowest surface temperature and heat flux were applied on three simulated models means for the second objectives.

Futhermore, the EPS Geofoam was used as heat insulator in the roof and wall structure. Three simulated models were fabricated, one with no insulation (reference) and the other two was insulate at different location which is at roof and wall structure respectively. These models are identical in sizes and materials. Indoor, ambient and surface temperatures as well as humidity were recorded on 10 hour basis. Then heat transfer was computed in order to determine the effectiveness of EPS Geofoam as heat insulator. The total heat reduction between wall insulated and roof insulated models were also compared in order to determine the best placement of thermal insulation in building component.

1.5 Significance of the Study

This study is to investigate and evaluate the impacts of coating colors on building thermal performance as well as the the effectiveness of EPS Geofoam as heat insulator in roof and wall structure. The findings of the study can contribute to selection of more appropriate materials for outdoor urban applications without altering the existing building geometry, and thus assist to fight the heat island effects, decrease the electricity consumption for cooling, fuel consumption and air pollution emissions as well as improve outdoor thermal comfort conditions.

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