

EFFECTS OF VARIATION OF CONSTRUCTION MATERIALS ON THERMAL
COMFORT USING CFD SIMULATION

IZZAT SAFUAN BIN ARIF

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‘I admit that had read this thesis and in my opinion this thesis was satisfied from the aspect of scope and quality for the purpose to be awarded Bachelor of Mechanical Engineering (Design and Innovation)’

Signature :

Supervisor’s Name :

Date :

I declare that this final year project (2) report entitled “Effects of Variation of Construction materials on Thermal Comfort Using CFD Simulation” is my own work except as cited in the reference.

Signature :

Name : IZZAT SAFUAN BIN ARIF

I/C No. : 870816-01-5619

Student ID : B040610155

Date : 8 October 2009

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ABSTRACT

Construction materials are materials that were used in construction field such as cements, sands, gravels, bricks and concrete. All of those materials have their own characteristics which can affect the thermal comfort of a building. Thus, the study on effect of variation of construction materials on thermal comfort of a building or room was conducted in order to achieve thermal comfort in a building or room. The methods used in completing this project includes the literature study on construction materials properties, how to minimize heat transfer from outside room through the wall, how to achieve thermal comfort using natural method, and materials selection. The CFD software that had been chosen, Fluent, were used as the simulation software. The ambient temperature of internal room was determined to measure comfort variation at different time of a day. From the analysis, a discussion is done to discuss the comparison of the materials of wall tiles, materials effectiveness and the limitation of the simulation. From the simulation analysis, porcelain ceramic shows the best result in reducing heat transfer through a wall. More effective material and method are recommended in order to reduce heat transfer through a wall.

ABSTRAK

Bahan-bahan pembinaan adalah bahan yang digunakan dalam bidang pembinaan seperti simen, pasir, kerikil, batu-bata dan konkrit. Kesemua bahan-bahan itu mempunyai ciri-ciri mereka sendiri yang boleh menjejaskan keselesaan terma sesuatu bangunan. Maka, kajian ke atas kesan variasi bahan-bahan pembinaan terhadap keselesaan terma sesuatu bangunan atau bilik dijalankan supaya mencapai keselesaan terma dalam satu bangunan atau bilik. Kaedah yang digunakan dalam menyiapkan projek ini termasuklah kajian ilmiah pada ciri-ciri bahan-bahan pembinaan, kajian tentang bagaimana untuk meminimumkan pemindahan haba dari luar bilik melalui dinding sesuatu bangunan atau bilik, kajian tentang bagaimana untuk mencapai keselesaan terma menggunakan kaedah semulajadi, pemilihan bahan-bahan. Perisian CFD dipilih, Fluent, diguna pakai sebagai perisian simulasi. Suhu ambien bilik dalaman didapatkan untuk mengukur variasi keselesaan pada masa berbeza dalam satu hari. Dari analisis, satu perbincangan dibuat bagi membincangkan perbandingan bahan-bahan jubin dinding, keberkesanan bahan-bahan dan had-had simulasi. Dari analisis simulasi, porselin seramik menunjukkan keputusan terbaik dalam mengurangkan pemindahan haba melalui satu dinding. Bahan-bahan yang lebih berkesan dan kaedah yang lebih berkesan adalah dicadangkan supaya dapat mengurangkan pemindahan haba melalui satu dinding.

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LIST OF SYMBOL

SYMBOL	TITLE
k	Thermal conductivity
Q	Quantity of heat
A	Surface area
ΔT	Temperature different
\vec{q}	Total heat flux
\dot{Q}_{cond}	Rate of conduction heat
h	Heat transfer coefficient
T_s	Surface temperature
T_b	Temperature of the fluid at bulk temperature
ν	Frequency
β	Constant
σ	Stefan–Boltzmann constant
λ	Wavelength
ϵ	Emissivity factor
K	Kelvin
$^{\circ}C$	Degree Celsius

CHAPTER I

INTRODUCTION

1.1 Introduction

Construction materials are material that use in construction field such as cements, sands, gravels, bricks and concrete. All of those materials have their own characteristics which can affect the thermal comfort of a building. The main characteristic that affect more is heat transfer behaviour of each those materials. Heat transfer behaviour of those materials was affected by thermal conductivity, k which presents how much it can absorb heat. The higher the k value, the higher a material can absorb heat.

Different methods have been investigated for achieving thermal comfort in a building with a natural way, did not use power source. Manufacturing materials or changing structure of the building materials to become high heat conductivity resistant materials is an important way to achieve the thermal comfort of a building. Before manufacture and change those materials, it requires a lot of literature study on construction material characteristic and heat transfer behaviour of the material.

This investigation is conducted to get the effects of variation of building materials on thermal comfort in a building or room. This investigation acquired simulation and numerical approach. The aim of this investigation is to find a way to achieved thermal comfort in a building or room either with create new construction materials or change structure and characteristics of current building material.

This Projek Sarjana Muda, (PSM) is a subject offered by Fakulti Kejuruteraan Mekanikal (FKM) as a compulsory subject for student to complete the Bachelor Degree Mechanical Engineering (Design and Innovation) course. It is one academic activity which is done by students individually and being examined and guided by FKM lecturer. The objective of PSM is to increase knowledge and student skills in settling problem by using the tools learned during throughout the course of

study and to implement all the skills involved. All skills include research, experiments, analysis and optimization are needed in finishing this project instead all of that skill had learn in previous semester. This is to produce skilled, quality and competent professional member.

1.2 Problem Statement

Global warming is one of the most talked about phenomenon nowadays. It has become a global threat to mankind's own survival. The evidence is already apparent. Polar ice caps are melting and the world suddenly feels hotter. Mankind's engineering has served for decades using nature friendly ways to do things in their everyday lives. This global warming is growing at alarming rate, and calls for people such as Leonardo Di Caprio and former US Prime Minister Al Gore about this grave matter. This problem is now a threat. This threat can be stopped. By using nature friendly products and methods, we can help reduce the effects of global warming and energy usage. The problem statement is:

- a) To find a natural ways to make a room or building comfort without using energy source.
- b) To explore passive cooling system that is going to help with thermal comfort by harnessing nature's secrets themselves.

1.3 Objective

The objectives of this project are:-

- a) To study the characteristics common building material.
- b) To study heat transfer involving these materials for a dwelling.
- c) To compare heat transfer behaviour after modifying the materials.
- d) To analyse the effect after modifying materials using simulation analysis.

1.4 Scope

- a) Literature study on building materials.
- b) Study on various method of minimizing heat transfer into a building.
- c) Simulation analysis on those materials using CFD.
- d) Comparative studies on heat transfer behaviour after modification.
- e) Apply the modified materials in CFD software and study the effect of thermal resistances.

1.5 Synopsis

The project begins with an understanding the title, “Effects of variation of construction material on thermal comfort of a prototype cell”. A research had been done for more understanding about this project. The research is on heat transfer behaviour of construction materials and construction materials properties. It includes on what and how can minimize heat transfer through a building in order to achieve thermal comfort. After all analysis done, a material is chosen to deeply study about its heat transfer behaviour, and the material is wall tile. The material’s heat transfer behaviour is simulated in simulation using Computational Fluid Dynamics (CFD) software which the selected software is Fluent.inc. An analysis of heat transfer of the material is done to get the conclusion from the result. A conclusion on simulation of materials heat transfer behaviour also done to summarise this project.

CHAPTER II

LITERATURE REVIEW

2.1 Construction Materials

Construction materials are any material which is used for a construction purpose. Many naturally occurring substances, such as clay, sand, wood and rocks, even twigs and leaves have been used to construct buildings. Apart from naturally occurring materials, many man-made products are in use, some more and some less synthetic. The manufacture of building materials is an established industry in many countries and the use of these materials is typically segmented into specific specialty trades, such as carpentry, plumbing, roofing and insulation work. This reference deals with habitats and structures including homes. There are many construction materials had been existed since a decade before today such as bricks, cement, tiles, concrete, metal and wood.

2.1.1 Brick

A brick is a block made of kiln-fired material, usually clay or shale, but also may be of lower quality mud. Clay bricks are formed in a molding (the soft mud method), or in commercial manufacture more frequently by extruding clay through a die and then wire-cutting them to the proper size (the stiff mud process). Bricks were widely used as a building material in the 1700, 1800 and 1900s. This was probably

due to the fact that it was much more flame retardant than wood in the ever crowding cities, and fairly cheap to produce.



Figure 2.1: Brick
(Source: Internet source, 30 July 2009)

2.1.2 Cement

Cement is a binder, a substance which sets and hardens independently, and can bind other materials together. The word "cement" traces to the Romans, who used the term "opus caementicium" to describe masonry which resembled concrete and was made from crushed rock with burnt lime as binder. The volcanic ash and pulverized brick additives which were added to the burnt lime to obtain a hydraulic binder were later referred to as cementum, cimentum, cäment and cement. Cements used in construction are characterized as hydraulic or non-hydraulic.

The most important use of cement is the production of mortar and concrete, the bonding of natural or artificial aggregates to form a strong building material which is durable in the face of normal environmental effects. Concrete should not be confused with cement because the term cement refers only to the dry powder substance used to bind the aggregate materials of concrete. Upon the addition of water and/or additives the cement mixture is referred to as concrete, especially if aggregates have been added.

The common cement used nowadays is Portland cement. Portland cement is the most common type of cement in general use around the world, because it is a basic ingredient of concrete, mortar, stucco and most non-specialty grout. It is a fine

powder produced by grinding Portland cement clinker, a limited amount of calcium sulphate which controls the set time, and up to 5% minor constituents.



Figure 2.2: Portland cement
(Source: Internet Source, 30 July 2009)

2.1.3 Tiles

A tile is a manufactured piece of hard-wearing material such as ceramic, stone, metal, or even glass. Tiles are generally used for covering roofs, floors, and walls, showers, or other objects such as tabletops. Alternatively, tile can sometimes refer to similar units made from lightweight materials such as perlite, wood, and mineral wool, typically used for wall and ceiling applications. Less precisely, the modern term can refer to any sort of construction tile or similar object, such as rectangular counters used in playing games. The word is derived from the French word *tuile*, which is, in turn, from the Latin word “*Tegula*”, meaning a roof tile composed of baked clay.

Tiles are often used to form wall and floor coverings, and can range from simple square tiles to complex mosaics. Tiles are most often made from ceramic, with a hard glaze finish, but other materials are also commonly used, such as glass, marble, granite, slate, and reformed ceramic slurry, which is cast in a mold and fired.

There are three types of tiles, wall tiles, floor tiles and roof tiles nowadays. These tiles made of many types of materials such as, porcelain ceramics, granite, sandstone, glass and stone. Porcelain is a ceramic material made by heating selected

and refined materials often including clay in the form of kaolinite to high temperatures.



Figure 2.3: Tiles



Figure 2.4: Special roof tiles

(Source: *Internet Source*, 30 July 2009)

2.1.4 Concrete

Concrete is a construction material composed of cement as well as other materials such as fly ash and slag cement, aggregate, water, and chemical admixtures. The word concrete comes from the Latin word "concretus" (meaning compact or condensed), the past participle of "concreresco", from "com-" (together) and "cresco".[8]

Concrete solidifies and hardens after mixing with water and placement due to a chemical process known as hydration. The water reacts with the cement, which bonds the other components together, eventually creating a stone-like material. Concrete is used to make pavements, pipe, architectural structures, foundations, motorways /roads, bridges/overpasses, parking structures, brick/block walls and footings for gates, fences and poles.[8]

Concrete is used more than any other man-made material in the world. [] As of 2006, about 7.5 cubic kilometres of concrete are made each year, more than one cubic metre for every person on Earth.

Concrete has relatively high compressive strength, but significantly lower tensile strength, and as such is usually reinforced with materials that are strong in tension (often steel). The elasticity of concrete is relatively constant at low stress levels but start decreasing at higher stress levels as matrix cracking develops.

Concrete has a very low coefficient of thermal expansion, and as it matures concrete shrinks. All concrete structures will crack to some extent, due to shrinkage and tension. Concrete which is subjected to long-duration forces is prone to creep. Tests can be made to ensure the properties of concrete correspond to specifications for the application.

2.2 Thermal Comfort

2.2.1 Introduction

Human thermal comfort is defined as the state of mind that expresses satisfaction with the surrounding environment. Maintaining thermal comfort for occupants of buildings or other enclosures is one of the important goals of design engineers.

Thermal comfort is affected by heat conduction, convection, radiation, and evaporative heat loss. Thermal comfort is maintained when the heat generated by human metabolism is allowed to dissipate, thus maintaining thermal equilibrium with the surroundings. Any heat gain or loss beyond this generates a sensation of discomfort. It has been long recognized that the sensation of feeling hot or cold is not just dependent on air temperature alone.

Factors determining thermal comfort include:

- Personal factors (health, psychology, sociology & situational factors)
- Air temperature
- Mean radiant temperature
- Air movement / velocity
- Relative humidity
- Isolative clothing
- Activity levels.

2.3 Heat Transfer of Material

Instead of achieving thermal comfort in a room or building, heat transfer of all material in those rooms or building need to be considered. Every material had different thermal conductivity coefficient, k .

Heat transfer is the transition of thermal energy from a hotter object to a cooler object. When an object or fluid is at a different temperature than its surroundings or another object, transfer of thermal energy, also known as heat transfer, or heat exchange, occurs in such a way that the body and the surroundings reach thermal equilibrium. Heat transfer always occurs from a higher-temperature object to a cooler temperature one as described by the second law of thermodynamics or the Clausius statement. Where there is a temperature difference between objects in proximity, heat transfer between them can never be stopped; it can only be slowed.

2.3.1 Types of Heat Transfer

2.3.1.1 Conduction

Conduction is the transfer of heat by direct contact of particles of matter. Conduction will take place if there exist a temperature gradient in a solid (or stationary fluid) medium. Energy is transferred from more energetic to less energetic molecules when neighbouring molecules collide. In other words, heat is transferred by conduction when adjacent atoms vibrate against one another, or as electrons move from atom to atom. Conduction is greater in solids, where atoms are in constant contact. In liquids (except liquid metals) and gases, the molecules are usually further apart, giving a lower chance of molecules colliding and passing on thermal energy. Conductive heat flow occurs in direction of the decreasing temperature since higher temperature is associated with higher molecular energy.

A rate of heat conduction through a medium depends on the geometry of the medium, its thickness, and material of the medium, as well as the temperature difference across the medium. This is because different material acquired different

thermal properties itself. Heat conduction is directly analogous to diffusion of particles into a fluid, in the situation where there are no fluid currents. This type of heat diffusion differs from mass diffusion in behaviour, only in as much as it can occur in solids, whereas mass diffusion is mostly limited to fluids.

Solid is usually the best conductors of thermal energy. This due to the way that chemically bonded, metallic bonds have free moving electrons which are able to transfer thermal energy rapidly through the metal. In other hands, liquid and gas are less thermal conductive because of the large distance between the atoms in the gas make fewer collisions between atoms. Conductivity of gases increases with temperature. Conductivity increases with increasing pressure from vacuum up to a critical point that the density of the gas is such that molecules of the gas may be expected to collide with each other before they transfer heat from one surface to another.

To quantify the ease with which a particular medium conducts, engineers employ the thermal conductivity, also known as the thermal conductivity or conduction coefficient, k . Thermal conductivity is the quantity of heat transmitted, due to unit temperature gradient, in unit time under steady conditions in a direction normal to a surface of unit area [tool]. Thermal conductivity, k is defined as the quantity of heat, Q , transmitted in time (t) through a thickness (Δx), in a direction normal to a surface of area (A), due to a temperature difference (ΔT)[Wiki]. Thus, conclude that the rate of heat conduction through a plane layer is proportional to the temperature difference across the layer and the heat transfer area, but is inversely proportional to the thickness of the layer.

$$\text{Rate of heat conduction} \propto \frac{(\text{area})(\text{temperature difference})}{\text{thickness}}$$

Fourier's law:

The law of Heat Conduction, also known as Fourier's law, states that the time rate of heat transfer through a material is proportional to the negative gradient in the temperature and to the area at right angles, to that gradient, through which the heat is flowing. We can state this law in two equivalent forms: the integral form, in which we look at the amount of energy flowing into or out of a body as a whole, and the differential form, in which we look at the flows or fluxes of energy locally.