**Faculty of Engineering**

# Ventilated Roof for Modern Low-cost House in Hot Humid Climate

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# Ventilated Roof for Modern Low-cost House in Hot Humid Climate

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## DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

……………………………

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## ABSTRACT

The overheating of indoor air temperature is one of the major concerns in a modern house design especially for the low-cost housing. Most of the occupants will feel uncomfortable when the indoor temperature is exceeding the level of thermal comfort. This result of the need to use mechanical means to cool the house, hence it surely incurs additional living cost to pay the electricity bill and maintenance cost. The overheating is a result from the hot air that trap in the house and the cause is due to poor of passive design; lack of ventilation provision in house design. It is important to remove the hot air from internal area to avoid any unforeseen event that could harm one's health; to avoid heat stroke from happening. To overcome this problem, the proposed ventilated roof is introduced and designed with more openings on the roof surface areas. This research was conducted and carried out to investigate the effect of openings on the roof surface towards the indoor temperature of a house in tropical climate areas. For this study, on-site experiment was conducted by building model houses with common roof and ventilated roof design under fully closed and fully opened condition. Air temperature and air velocity were recorded and the data was used as an input to the CFD Simulation. The CFD simulation was carried out for validation purposes. Once validated, the CFD simulation was proceeded with model house with different pitch of roof. The CFD simulation on Betong's house was conducted with ventilated roof tiles design. From the findings, it was concluded that model house with ventilated roof tiles design recorded lower indoor temperature as compared to common roof. In conclusion, the passive design of modern house is improved through the adoption of the ventilated roof tiles design, which it enhances the removal of the hot air and reduce air temperature inside the house.

**Keywords:** Passive design; ventilated roof; CFD simulation

***Bumbung Pengudaraan untuk Rumah Kos Rendah Moden dalam Cuaca Lembab Panas***


## *ABSTRAK*

*Suhu di dalam rumah yang terlampau panas mendatangkan kebimbangan kepada penduduk perumahan kos rendah. Kebanyakan penduduk merasa tidak selesa disebabkan suhu di dalam rumah melebihi paras suhu keselesaan terma. Penduduk akan mula bergantung kepada sistem pengudaraan mekanikal yang menggunakan tenaga elektrik, di mana kos bil elektrik dan penyelenggaraan akan meningkat. Kenaikan suhu di dalam rumah adalah disebabkan udara panas yang terperangkap disebabkan oleh rekabentuk pasif yang lemah; kekurangan sistem pengudaraan. Udara panas yang terperangkap di dalam rumah perlu dibebaskan kerana boleh menyebabkan strok haba. Untuk mengatasi masalah ini, kajian rekabentuk bumbung pengudaraan menyediakan lebih banyak bukaan di atas permukaan bumbung sebagai laluan untuk udara panas keluar dari dalam rumah. Ujikaji terhadap model-model rumah telah dijalankan ke atas rekabentuk bumbung biasa dan bumbung pengudaraan dengan keadaan pintu dan kesemua tingkap tertutup dan terbuka. Suhu udara dan kelajuan angin direkodkan dan data tersebut digunakan sebagai input kepada simulasi CFD. Simulasi CFD dijalankan untuk pengesahan kajian. Selepas pengesahan kajian dijalankan, simulasi CFD diteruskan dengan sudut bumbung rumah yang berbeza. Kajian simulasi CFD diteruskan kepada rumah kos rendah yang terletak di Betong, Sarawak dengan rekabentuk bumbung pengudaraan. Hasil kajian mendapati bahawa rumah yang menggunakan bumbung pengudaraan mencatatkan suhu yang lebih rendah berbanding rumah yang menggunakan bumbung yang biasa. Kesimpulannya, rekabentuk pasif rumah moden dapat ditambahbaik dengan penggunaan bumbung pengudaraan kerana ia dapat membantu untuk mengeluarkan udara panas dan menurunkan suhu udara dalam rumah.*



**Kata kunci**: *Rekabentuk pasif; bumbung pengudaraan; simulasi* CFD

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## LIST OF SYMBOLS AND ABBREVIATIONS

| | |
|---|---|
| am | Ante Meridiem |
| º | Degree |
| ºC | Degree Celsius |
| °N | Degree North |
| CFD | Computational Fluid Dynamic |
| kW | Kilo Watt |
| $kWh/m^2$ | Kilo Watt Hour Per Meter Square |
| m/s | Meter Per Second |
| % | Percent |
| pm | Post Meridiem |
| PPR | Program Perumahan Rakyat |
| Unimas | Universiti Malaysia Sarawak |

# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction

Malaysia is located at 3 °N at the equatorial zone and experiencing tropical climate condition throughout the year. The country is considered as one of uncomfortable climate zones as compared to moderate and cold climate zone (Al-Obaidi et al., 2014a). The temperature all year round is ranging between 26 °C to 29 °C with average rainfall of 250 cm and average relative humidity between 70% to 80% (Suparta & Yatim, 2017). Malaysia is exposed to a very high amount of solar radiation ranging around 1400 to 1900 kWh/m$^2$ (Soonmin et al., 2019). It is known that the most crucial impact of the climate in Malaysia buildings are high solar radiation's intensity and high daily air temperature (Jamaludin et al., 2015; Soonmin et al., 2019). The driest months would be between June to August, where the temperature would be hot and dry during daytime and night time (Malaysia Meteorological Department, 2014).

It is known that the hottest time of the day is between 11.30 am to 4.30 pm (Roslan et al., 2015). The average daily sunshine duration was measured between the range of six to seven hours per day with an average of 26 °C of daily temperature and low wind velocity (Soonmin et al., 2019; Suparta & Yatim, 2017). The recommended comfortable indoor air temperature is ranging from 24 °C to 26 °C (Department of Standards Malaysia, 2017). The occupants would start to depend on the mechanical ventilation system for cooling purposes if the temperature is beyond the level of thermal comfort. Roslan et al. (2015) describe that the concrete terrace house is thermally comfortable for only a few hours per day especially in the morning.

Sarawak is one of the states in Malaysia and the total population in Sarawak was increased from 2,071,506 to 2,471,140 in the year of 2000 and 2010 (Department of Statistics Malaysia, 2015). The rapid growth of populations in Sarawak has expanded the housing development industries, which has divided into three categories such as low-cost, medium-cost and high-cost housing. One of the Government's initiatives to help low-income family to own a house is through *Program Perumahan Rakyat* (PPR). During 10th Malaysia Plan, the PPR program has expanded to Sabah and Sarawak. As of the 11th Malaysia plan, the starting price of the house is around RM30,000 to RM35,000 per unit for Peninsular Malaysia while RM42,000.00 per unit for Sarawak and Sabah (Ministry of Housing and Local Government, 2018). Under the 11th Malaysia Plan, a total of 606,000 numbers of houses to be constructed for low and middle-income groups.

The low-cost house is designed based on the standard set by the Ministry of Housing and Local Government and local city council. The low-cost house typically designed with a smaller built-up area and cheaper building materials (Ajim et al., 2017; Arshard & Hassan, 2016). The low-cost house is considered unsuccessful in providing good thermal comfort towards the occupants due to its poor design (Ibrahim et al., 2014a). The authors also stressed that the low-cost house failed to provide acceptable thermal comfort to the occupants. Studies found that the urban and modern residential recorded indoor air temperature up to 32.6 °C, which is higher than recommended thermal comfort air temperature (Jamaludin et al., 2015).

The roofing system represents about 70% of the heat gain in building envelope element. The other studies carried out by researchers concluded that the heat transmitted into an indoor area through the roof and trapped was the one of the main factors of discomfort level in the non air-conditioned building (Azzmi & Jamaludin, 2014). In addition, according to Ibrahim et al. (2014b), the hot air cannot exit the house and become trapped due to lack of ventilation provision. The roof surface is affected by heat transmission, especially during clear sky condition when the amount of solar radiation can reach up to 1 $kW/m^2$ and the absorption is ranging from 20% to 90% of the amount of solar radiation in its fabric (Bakkush et al., 2015; Suehrcke et al., 2008). Roof is the building elements that contributes to the production of heat gains and is exposed to the direct sun (Lubis & Koerniawan, 2018).

According to Lau et al. (2008) and Roslan et al. (2015), about 85% of the house in Malaysia are using concrete tiles as their roofing material, followed by clay tiles and metal sheet with 10% and 5% respectively. The metal deck sheet is the typical roof material for low-income house. The roofing system of the low-cost house typically designed with a low roof angle between 10° to 15° (Ibrahim et al., 2014a). The roof material used are typically metal deck sheet. This material permits high transmission of solar radiation, hence creates a sauna effect and induces uncomfortable to the occupants (Al-Obaidi et al., 2014b). However, this material is cheap and easily available in the market.

Ibrahim et al. (2014a) identified that the low-income house suffered overheating during daytime due to its poor design constructed with no ceiling and very poor in roof insulation. The indoor air temperature of a modern low-cost house is higher than the occupant's thermal comfort range (Roslan et al., 2015). The authors stressed that the causes of overheating also known due to its roof pitch and poor ventilation provision on the house's wall. The overheating is usually happened due to the hot air trapped inside the house. The source of the hot air mostly comes from the heat that has been transmitted roof surface and then transferred to the lower area. The roofing system is one of the building envelope components apart from the walls, floors, windows and doors. The orientation and location of these building envelopes play an important role in reducing the indoor temperature by maximizing the use of natural resources as cooling component. Previous studies showed that the building envelope to minimise the use of energy in a building by maximizing the natural ventilation (Apat, 2014).

Without a proper ventilation system, the house would suffer from the overheating. The overheating surely could cause discomfort state to the occupants; hence it would generate the needs for cooling system such as air-conditioning system, exhaust fans and so forth. The high transmission of solar radiation affecting occupant's level of comfort. Most of the occupants are well-versed with types of cooling system to cool down their residential and commercial building. Not to mention the energy used to generate the cooling system represent the biggest energy load. This matter arises due to the concern on modern comfort standards, social customs and design practices, which made the mechanical cooling is one of the necessary requirements (Rahman et al., 2013).

Based on report from Energy Commission (2014), commercial buildings use the electricity up to 38,645 GWh, while residential buildings consume about 24,709 GWh. The same report recorded the highest daily electricity demand amounting 345.25 GWh in 2013, which was increased by 5% from the previous year. In addition, the annual electricity demand increases by 3.6%, from 108,473 GWh in 2012 to 112,358 GWh in year of 2013 (Energy Commission, 2014). The increasing of energy demand is due to the increasing of number for commercial and residential buildings and rapid population growth as well as climatic changes (Rahman et al., 2015). The authors also addressed that most of electricity use for ventilation system and cooling purpose. The cooling system is important to achieve occupant thermal comfort. Due to the increase in cost per rate of electricity, designer nowadays become more aware to use natural resources in daily lives (Roslan et al., 2015). The designer has started to look for application of natural resources for ventilation and cooling purposes inside a building to achieve occupant thermal comfort.

One of the good thermal comfort houses examples is the traditional Malay house. It was first introduced in Malaysia during the 1800s. The traditional Malay house is constructed with a lightweight material including minimum mass and voids, using high insulation materials and low thermal capacity, which are appropriate for thermal comfort in our climate (Ibrahim et al., 2015). Thermal capacity is defined as amount of heat on a body to raise temperature. Higher thermal capacity material would have greater amount of heat stored inside. Most of the traditional Malay house used timber as the main material, while the roof is made from the leaves of the *Arecaceae* or the common name is *Nypa fruticans*. Undoubtfully, both are considered good in insulation and providing natural ventilation. In addition, the traditional Malay house typically from the lightweight material (Ibrahim et al., 2015). The characteristic of the materials come with a low thermal capacity, which only allow a little amount of heat and easily cools at night time.

Apart from that, the traditional Malay house also has a higher ceiling, giving a larger space in the attic area and at the same time allows the hot air to rise and exit via the spaces between *Nipah* roof arrangement. The design such as higher ceiling and build higher from ground level also enhances the stack effect to occur effectively. It was found that the traditional Malay house is cooler than a modern house during daytime. Previous study concluded that the indoor air temperature in a traditional Malay house is cooler than outdoor climate up to 3.0 °C differences and maintaining average speed or air velocity of 0.10 m/s

(Prasetyo et al., 2014). It was found the idea of adapting the stack effect roof design in Malay house can help to minimise the hot air in a building (Ramli, 2012; Roslan et al., 2015). Many researchers agreed that the traditional Malay house is one of the best passive designs that enhance sustainable house (Ibrahim et al., 2015; Kamal et al., 2004; Ramli, 2012). The *Nipah* roof is good in maintaining good climatic condition inside the house. According to Roslan et al. (2015), the *Nipah* roof is having a lower thermal capacity, hence provide good insulation against heat. The *Nipah* roof provide a good climatic inside the house as the roof has the ability to cool the room during day time and warm the house at night (Ibrahim et al., 2015).

The modern concrete houses heat up during daytime and hardly to cool during night time (Ajeel & Yusof, 2016; Wahab & Ismail, 2012). Malaysian houses have problems with night ventilation because most residents usually open their house's windows during day time and close at night. This would lead to the high usage of electricity to achieve indoor thermal comfort at night time. Roslan et al. (2015) stressed that lack of ventilation provision and poor of passive design are the main causes of overheating. It is essential to investigate the passive design, especially at the top part of the house, such as the roofing system design that could allow or improve the natural ventilation. In this study, the roof was designed to investigate on the effect of the openings on the roof surface with the indoor air temperature.

## 1.2 Problem Statement

Building occupants especially for modern houses in tropical climate normally experienced higher indoor temperature during daytime. This is due to the poor passive design of the modern house these days. Nowadays, modern low-cost house is built with poor architectural specifications, lack of natural ventilation and unsuitable with prevailing climatic condition which has result to the extreme indoor air temperature and comfort (Bhikhoo et al., 2017). The overheating inside modern house would lead to the increasing energy consumption to operate the air-conditioning unit (Elborombaly & Prieto, 2015). Natural ventilation system would help to reduce indoor air temperature naturally. From previous studies, attempts have been made to emphasis the reduction of indoor air temperature through opening of windows, doors and louvers (Ibrahim et al., 2014a; Roslan et al., 2015).

Roofing system plays an important part of the house that contribute to the thermal comfort of the indoor environment. The heat from solar radiance transmits into internal area through the roof surface. According to Zingre et al. (2015), roof could reduce up to 6% of the annual heat entry through roofing system during daytime but become an obstacle for heat loss at night time. Without proper ventilation, the trapped hot air inside the house escape via the smaller opening provided at the ridge vent, which located at the end and at the centre of the roof.

Roslan et al. (2015) addressed that modern house is built with lack of ventilation system especially at the roofing area. Roofing materials also play important part in allowing the amount of heat transferred into the house. The clay roof tiles also one of modern roof materials, but the cost per unit is expensive compared to the metal deck or zinc roof. Although metal deck and zinc roof are cost saving material for a modern house, but it has higher thermal conductivity than clay roof tiles. This is also one of the causes of the overheating inside the house when a large amount of energy from solar radiation is absorbed and transmitted into the lower area. The turbine ventilation in the other hand could help to remove the trapped hot air, but it is less preferable due to additional cost incur in operating and maintaining the unit. The traditional *Malay* house is one of the best examples providing