EFFECTS OF HIGH MASS ON THERMAL PERFORMANCE OF HERITAGE BULDINGS IN GEORGE TOWN, PENANG

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ABSTRACT

In George Town, Penang, the distinctive features of its heritage colonial buildings are its large thermal mass and lofty ceiling heights. While differing greatly from the styles of Malaysian vernacular architecture – often defined by the traditional Malay kampung house – these western-inspired, clay-and-stone buildings have been claimed to be designed as such in order to provide comfortable indoor thermal conditions to its inhabitants by passive means. However, there have been relatively few studies published in relation to the thermal performance of these buildings in context of the hot and humid climate of George Town, Penang. This research investigates the unique features of several colonial heritage buildings and takes note of the thickness of its external walls. The thermal performance of the selected buildings is then assessed by comparing air temperature readings which were recorded indoors (Ti) and outdoors (To); simultaneously. Results show that temperature swings were greatly reduced in all heritage buildings, especially at midday when To reaches a high maximum. Among all samples, the building with thickest exterior walls (of 375mm in average) showed the most favourable average indoor-outdoor temperature difference (Ti-To) of -0.94°C during peak hour, as well as the most percentage of hours that indoor air temperature remains below that of the outdoors (Ti < To).

Keywords: Penang heritage buildings, thermal performance, hot and humid climate.

1. Introduction

Energy use in Malaysia, which follows urban development is seen to have risen steadily since the 1980's, to a high value of 15072 MW (of electricity) in the second quarter of 2010 (Department of Statistics Malaysia, 2011). In fact, over half of the country's increasing demand for electricity is spent in the commercial and residential sector, of which a large portion is used on buildings (Electricity Supply and Market Regulation Department, 2010 & 2011). From that amount, 44.23% to 64% of the annual electricity consumption in a building is allocated to operating air conditioning and other interior cooling mechanisms (Chan, 2004 and Singh, 2006).

This large consumption of energy for cooling stems from the problem of designing buildings which are ill-adapted to the Malaysian local climate (Abdul Rahman et al., 2009). Often, typical contemporary buildings possess little of the characteristics found in Malaysian vernacular architecture which would otherwise make it more climate-appropriate. Instead, current commercial and residential buildings are designed to maximize space and minimize construction costs; while sacrificing energy efficiency and occupants' comfort. 'Quick' fixes are then applied post-construction, such as by installing air conditioning to provide the much-needed indoor air movement, lower temperature and relative humidity – at the risk of increased electricity usage.

Therein lies a need to re-examine and implement passive design into contemporary buildings; both residential and commercial. Examples of such design can be seen in heritage traditional, and colonial architecture. However, considering the context of the growing urban climate, designs that mimic the lightweight structure of timber traditional Malay architecture would appear impractical. Adaptations from heritage colonial buildings on the other hand, would easily comply with today's building regulation in towns and cities. Regardless, there has been only a few studies conducted in relation to the thermal performance of the passive design architecture example that is the heritage colonial building. The location of this research is in George Town, Penang – a UNESCO World Heritage Site in Malaysia (apart from Malacca). The city alone has over 4000 conserved buildings (more than twice of that in Malacca) – a large number of which existing since the colonial era (Mohd. Sharif, 2010). This research investigates a distinctive feature of Penang's conserved colonial buildings that may influence its supposed thermal performance; its large thermal mass (via thick exterior walls). Its objectives are:

1) to measure and compare the thickness of exterior walls of several heritage colonial buildings in George Town, Penang; and
2) to assess the thermal performance of each building by comparing simultaneous indoor and outdoor air temperatures.

2.Literaturereview

Thermal Comfort in Penang, Malaysia

Firstly, in designing comfortable and energy-efficient buildings, it is vital to gauge the requirements of thermal comfort in the local context before making decisions in design. The island of Penang, while subjected to the hot and humid climate of tropical Malaysia, is also affected by its vicinity to the coast. Temperatures within the urban areas are often higher than that recorded on the mainland; sometime reaching a peak of 34°C during the day. In George Town, temperature generally ranges from 29°C to 34°C during the day, and 26°C to 29°C at night. On hottest days, solar radiation readings can exceed 6.1 kWh/m² around midday to early afternoon hours (Malaysian Meteorological Department, 2009).

Given the climatic conditions in Penang, thermal comfort in a building (apart from the occupants' clothing and metabolic rate) can be determined by the indoor air temperature, mean radiant temperature, air speed and relative humidity (Abdul Rahman, 2000 & ASHRAE, 2010). Previous studies have shown that while some international standards may apply, adaptive thermal comfort implies that Malaysians may tolerate higher air temperature and relative humidity readings than those suggested in practice. ASHRAE Standard recommends a comfortable temperature range of 23-26°C for summer conditions, with a relative humidity level of 50%. Despite that, Malaysians have been shown to be comfortable in temperatures ranging 25-30°C with relative humidity between 45% and 90% (Salleh, 1989; Inangda, 1991; Inangda et al., 1996; Maznah et al., 1999 and Abdul Rahman, 2000). However, more recently, a recommended operative temperature was established in the Building Energy Efficiency Technical Guideline for Passive Design by the Building Sector Energy Efficiency Project Malaysia to define the upper limit of indoor air temperature for thermal comfort; which is 28.25°C (BSEEP, 2013). This figure would define Malaysian building occupants' comfort limit more accurately.

Designing for Thermal Performance

The thermal performance of a building (i.e. the ability of a building to provide thermal comfort to its occupants) is determined by the components of its envelope (Mirrahimi et al., 2016). Factors such as the building form, width, length, height, orientation, material, insulation, glazing type and window-to-wall ratio (WWR) all play a part in limiting heat transmission into its interior spaces. According to Abdul Malek Abdul Rahman, a summary of appropriate design for buildings in the hot and humid climate should include attempts to: limit solar radiation (into the building's interior), encourage evaporative cooling, encourage air movement and also cooling, by stack effect (Abdul Rahman, 2009). As such, it was found that to improve thermal performance, orientation of a building in Penang was recommended to be north/south, while WWR be kept to 15% maximum (Al-Tamimi, 2011). Shading for window openings on the other hand, is said to be effective at minimum 1:1 ratio in terms of horizontal projection to window height (BSEEP, 2013).

Recommendations for thermal mass however has not been thoroughly discussed in the Malaysian context. In texts describing traditional Malay architecture, it is shown that extensive use of 25mm to 40mm-thick timber for exterior walls is preferred (Lim, 1987 and Hassan & Ahmad Nawawi, 2014). However, this choice of low building mass (coupled with Malaysia's existing climate) results in very high indoor air temperatures; reaching 33-35°C during the day (Hassan & Ramli, 2010). In other cases, researchers have recorded indoor air temperature between 23.5°C and 33°C for similar traditional homes (Kubota & Toe, 2012). Of typical concrete terrace houses, previous studies show that the common wall thickness measurements were between 140mm and 240mm Recorded indoor air temperature for those buildings were between 26°C and 34°C (Kubota et al., 2009).

Table 1: Heat transfer formula

$H = \dfrac{k\,AT\,(t1-t2)}{L}$	
k = material conductivity	A = area
T = time	(t1-t2) = temperature difference between wall's surfaces
L = wall thickness	

Table 1 shows the formula used to calculate heat transfer between the two surfaces of a building's wall. Considering that one of its factors to be thickness – apart from selecting the right material to form the building envelope – determining the appropriate thickness of the wall construction is also vital in reducing heat gains.

While high thermal mass is not a common choice for Malaysian buildings (of small to medium scale), examples are found in other countries of similar climates. In the past, the use of thick walls has been seen to limit heat transfers in residential buildings belonging to the hot climate of Bangladesh. According to Mallick, a house with 375mm-thick walls provided the most comfortable temperature range; compared to other thinner constructions (Mallick, 1996). Similar notions were made regarding buildings in the hot climates of China, Singapore and Dubai where buildings with thicker walls were preferred when there was need to reduce indoor air temperature (Niu, 2004; Wang & Wong, 2007; Gong et al., 2012 and Al Masri & Abu Hijleh, 2012).

3. Field Measurements Of Selected Penang Heritage Buildings

A large number of Penang's built heritage consist of Chinese shophouses and medium-to-large buildings from the colonial era. These buildings, although offering little resemblance to traditional Malay architecture, have been indicated to be designed with respect to the local climate (Yoke, 1994; Hassan 2001; Ahmad, 2011 and MPPP, 2013). In saying that, one distinctive and contributing element to the buildings' implied thermal performance is its thick, clay brick and lime plaster exterior walls. Table 2 contains brief descriptions of selected heritage buildings that were investigated in this research (all of which possessing the above trait), with indications made to the rooms in which thermal data was recorded.

Table 2: Case study buildings

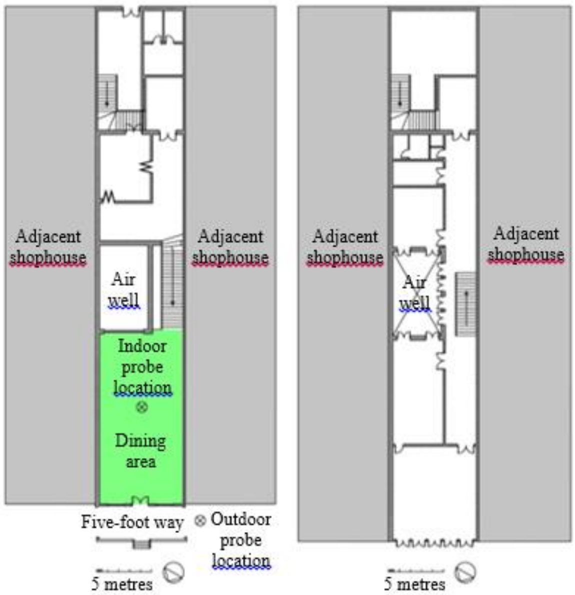
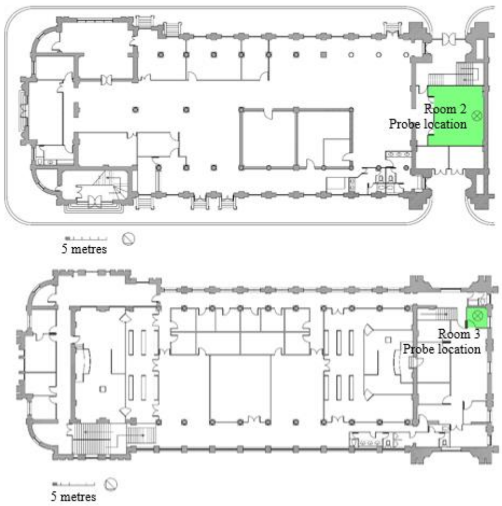
Building	Description
	
Edelweiss café, Lebuh Armenian Abbreviation: EC	Material: Clay brick & lime plaster Colour: Yellow Room area: 117m² Room height: 4.0m Window area: 7.5m² Average room wall thickness: 300mm
	
Jabatan Hal Ehwal Agama Islam Pulau Pinang, Lebuh Pantai Abbreviation: JH1 and JH2	Material: Clay brick & lime plaster Colour: White Room area: 38.1m² and 5.0m² Room height: 4.6m and 4.8m Window area: 0m² and 3.1m² Average room wall thickness: 152mm and 225mm

Table 2 (Continued)

Balai Bomba dan Penyelamat,
Lebuh Pantai
Abbreviation: BB1 and BB2

Material: Clay brick & lime plaster
Colour: White
Room area: 129.9m² and 77.7m²
Room height: 4.2m and 4.2m
Window area: 26.6m² and 18.0m²
Average room wall thickness: 375mm and 375mm

Town Hall,
Jalan Padang Kota Lama
Abbreviation: TH1 and TH2

Material: Clay brick & lime plaster
Colour: Yellow
Room area: 75m² and 71m²
Room height: 5.4m and 5.4m
Window area: 24.8m² and 24.8m²
Average room wall thickness: 252mm and 244mm

George Town World Heritage Incorporated,
Lebuh Acheh
Abbreviation: GT1 and GT2

Material: Clay brick & lime plaster
Colour: White
Room area: 9.5m² and 35.3m²
Room height: 4.2m and 4.2m
Window area: 1.8m² and 5.4m²
Average room wall thickness: 300mm and 309mm

The case study buildings chosen were of different sizes and function, but follow the requirements where they were:

1) Located within the UNESCO World Heritage Site in George Town
2) Conserved buildings with minimal renovation

3) Significant and relevant buildings which are unlikely to be demolished
4) Of mainly clay bricks and lime plaster with large thermal mass; >200mm exterior walls
5) Not air-conditioned (at least where air temperature readings were recorded)

Air temperature measurements were taken 1 metre above floor level – at every 15-minute interval – for one week, in locations indicated on the floor plans in Table 2. Equipment used were BABUC/A and BABUC/M data loggers; fitted with calibrated air temperature, relative humidity and mean radiant temperature probes.

Results and Discussion

Results gathered from field work generally show that indoor air temperature (Ti) is greatly reduced during the day. At night on the other hand, Ti tends to exceed outdoor temperature (To). This creates a moderated Ti profile in all buildings of the case study. Maximum To is seen to occur between 2PM and 4.30PM with little exceptions. Max Ti on the other hand, occurs later between 4PM and 6.30PM, indicating a heat transfer delay of around 2-3 hours. Min Ti in the buildings often occur between 8AM and 11AM, as a result of lingering heat from the night before.

Relative humidity was also well-regulated in all buildings, given that indoor relative humidity levels (RHi) displayed smaller fluctuations than that of the outdoors (RHo).

Table 3: Field measurement results

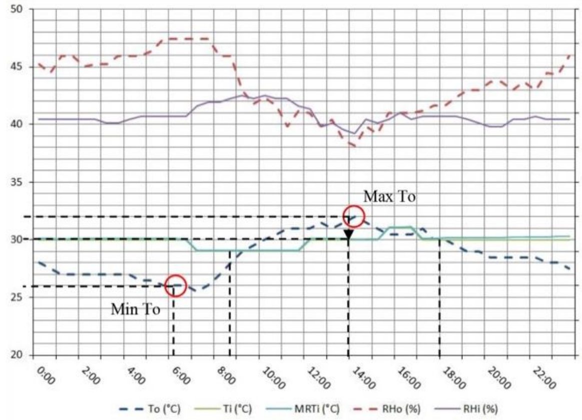
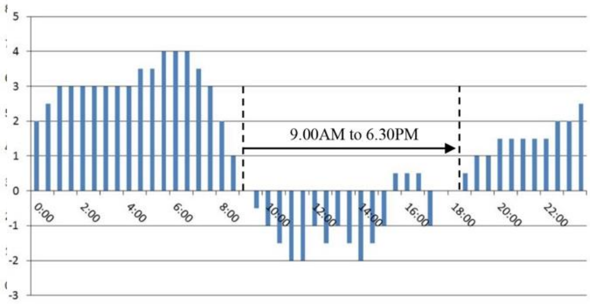
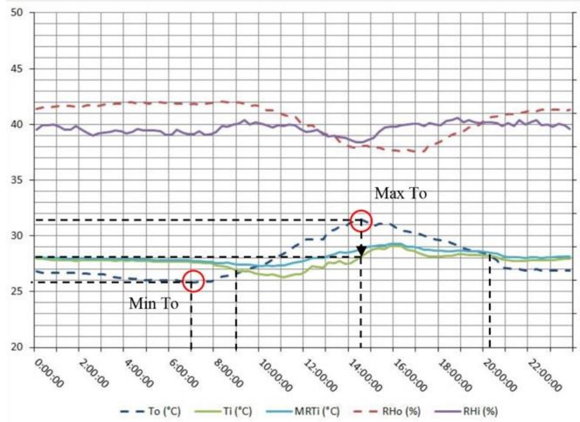
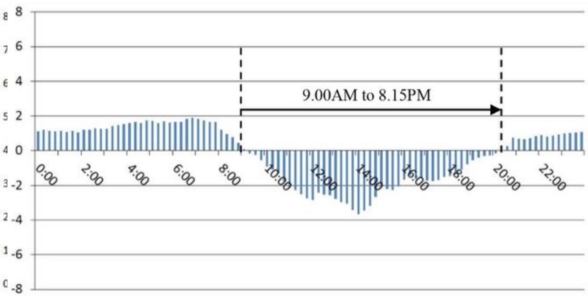
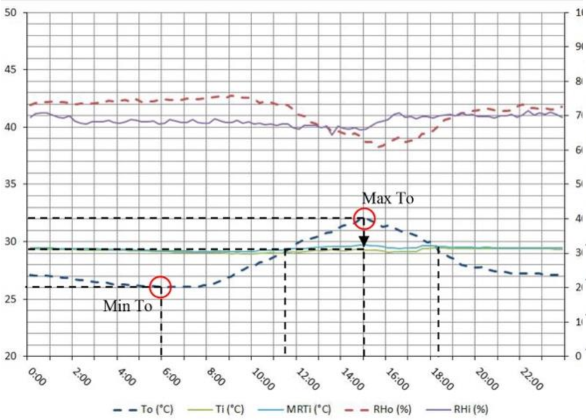
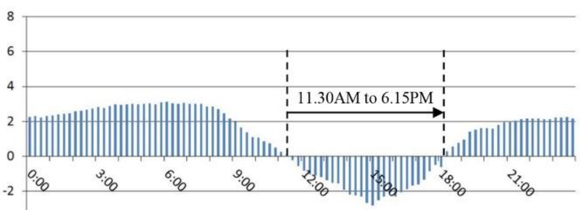
Room	Mean air temperature and relative humidity	Ti-To
EC		

Table 3 (Continued)

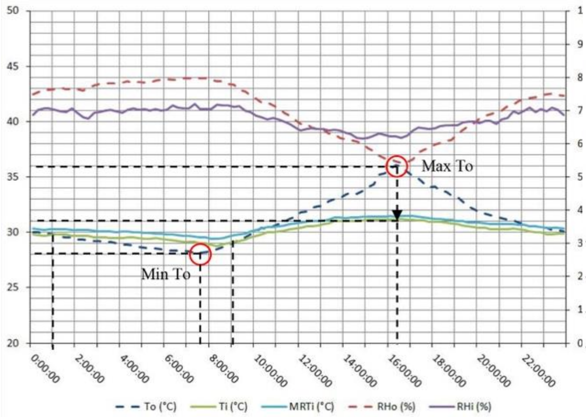
JH1		

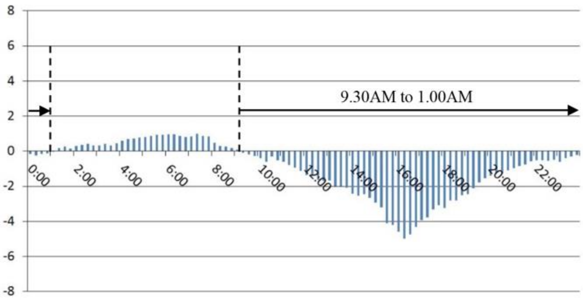
JH2



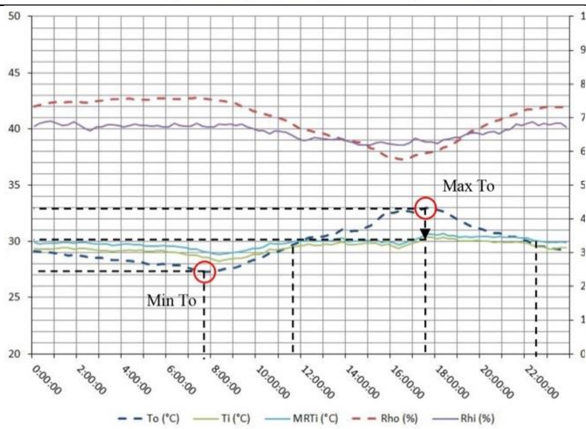


BB1





BB2



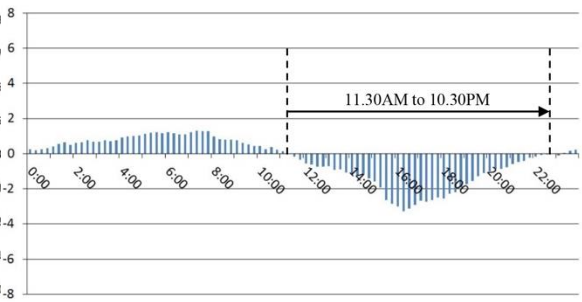
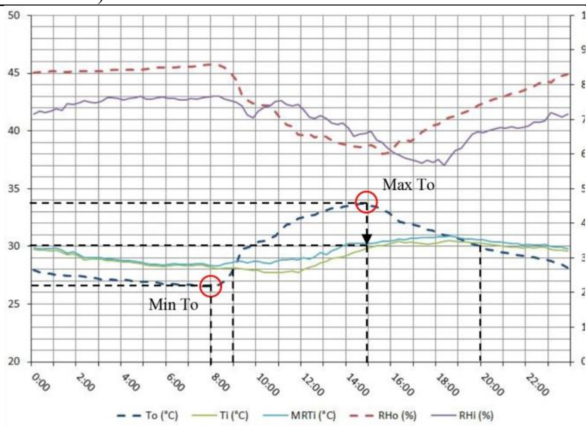
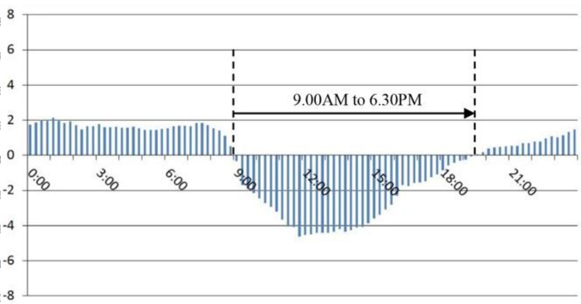


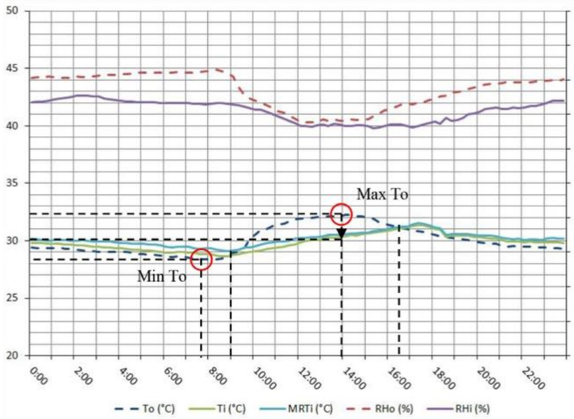
Table 3 (Continued)

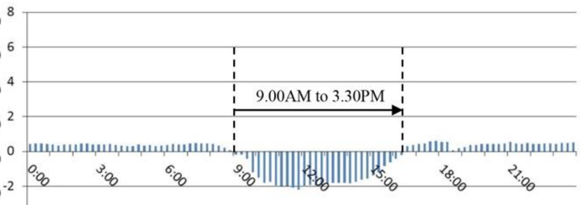
TH1



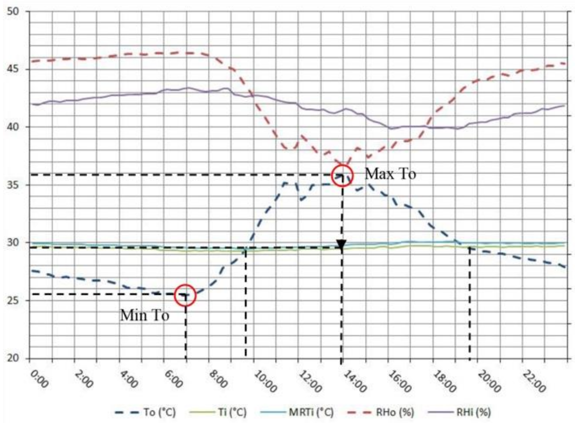


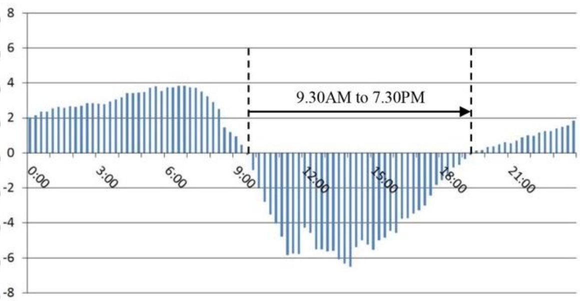
TH2



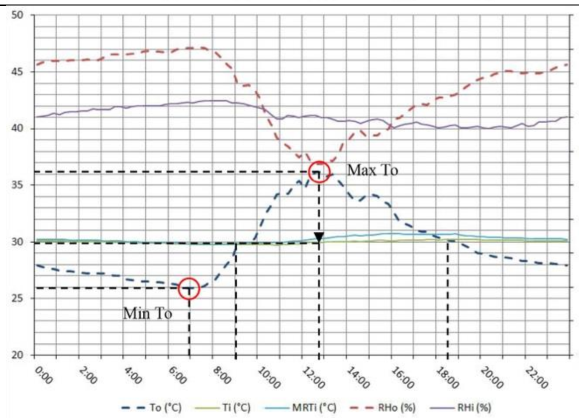


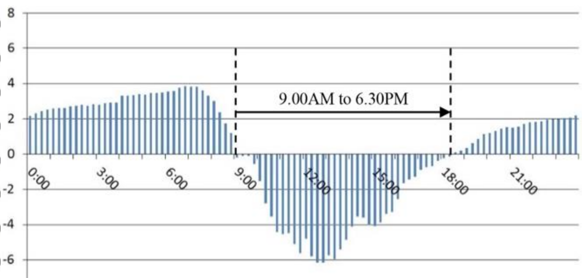
GT1





GT2

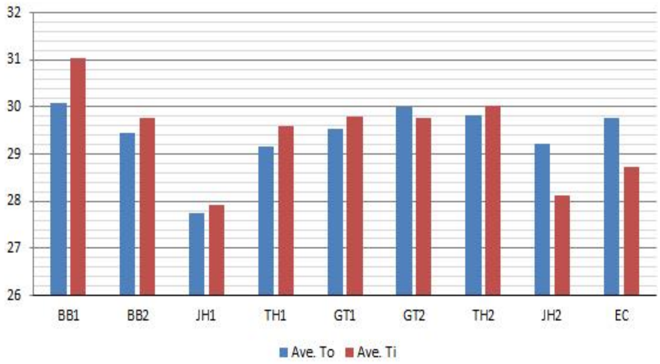


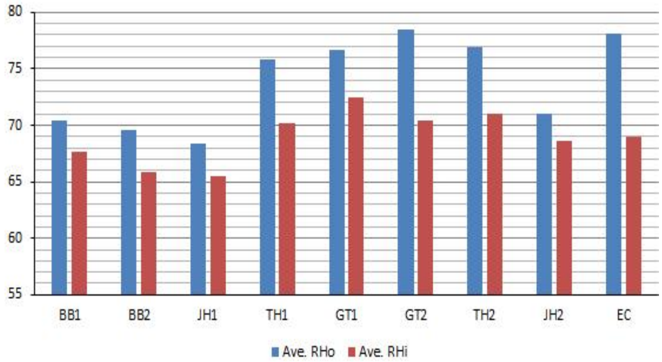


From the 24-hour averaged readings in Table 3, it is shown that Ti-To reduction was most visible in GT1 and GT2 (To of 36°C and Ti of 30°C). While this could mean that the GTWHI building was designed best to reduce overheating from outdoor heat gains, its Ti readings were not the lowest (recorded at 29°C to 30°C during an average 24 hour period) and its night time Ti were among the highest.

In order to clearly rank the buildings' thermal performance, the environmental data collected over the week-long period was averaged to a single Ti and To value for each room. Hours where Ti recorded below To level were also logged. Table 4 shows the summarized results.

Table 4: Summarized field measurement results





Room	BB1	BB2	JH1	TH1	GT1	GT2	TH2	JH2	EC
% hours Ti < To	66.7%	50%	45.8%	43.8%	41.7%	39.6%	31.3%	28.1%	27.1%

Lowest average Ti was recorded in room JH1 on the ground floor of the Jabatan Hal Ehwal Agama Islam Pulau Pinang. Interestingly, both GT1 and GT2 rooms of the George Town World Heritage Incorporated office ranked middle, in terms of average Ti; this is most likely due to its high night temperatures which raised its overall value. Highest average Ti was recorded in BB1, located on the first floor of the Balai Bomba dan Penyelamat building. However, considering its average To level to be the highest; at 31°C, temperature reduction (Ti-To) is most apparent for BB1.

In addition to that, BB1 logged the most number of hours that Ti remained below that of To during the whole period of data collection. This was followed by BB2, located on the second floor of the same building. It is worth noting that both rooms had the thickest exterior wall measurement, as well as among the largest unpartitioned floor area. Further research would be necessary to weigh other variables which may have affected the rooms' thermal performance such as window size and potential air movement.

4. Conclusions

From conducting this research, it is found that the room with 375mm thick exterior walls provided best thermal performance in the context of Penang, Malaysia. Daytime indoor temperature was significantly reduced, with obvious lag in heat transfer.While comparisons of thermal performance between each room show that average Ti were above the BSEEP recommended 28.25°C, it remains suggestive of the readings being generally lower than that which was found in previously researched traditional Malay and contemporary terrace houses.

The issue which would need to be addressed in terms of local buildings with high thermal mass would be night time cooling; as demonstrated by every measured room in the case study. The storage of heat in the building's heavy structure would require a method of ventilation which can purge warm air from its interior spaces at night.

Limitations of this research was that only one room was permitted access for measurement-taking in each building. The location and sizes of the rooms were different, as well as its exterior wall vs. room area ratio. For future research, as well as addressing its limitations, influence of other thermal variables such as window size and ventilation would need to be investigated, or altogether removed – in order to properly assess the sole effect of exterior wall mass on thermal performance of buildings.

Acknowledgement

The authors would like to express appreciation to Universiti Sains Malaysia (USM) and the Institute of Postgraduate Studies USM Fellowship Scheme for supporting this research. Thank you also to the caretakers of all buildings involved for the cooperation given throughout the study.

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