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Assessment of Passive Thermal Performance for a Penang Heritage Shop house

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Abstract

In recent years, Malaysia has seen an increase in energy consumption by buildings from all sectors. A significant portion of the energy consumed annually is spent to cool residential and commercial buildings. However, there is possibility that the country's overall energy usage may be reduced, provided that steps are taken to minimize cooling loads in buildings via passive means. Considering Malaysia to be a country of hot-humid climate, many modern building designs have been observed to ignore the general characteristics of the region's vernacular architecture. These are the key elements which help to reduce solar heat gains during the day. Properly conserved heritage buildings however, are seen to possess some of these qualities which may allow them to remain cooler than their modern counterparts under similar conditions. This paper discusses the thermal performance of a heritage shop house in Penang, Malaysia, which uses passive cooling. Aspects which are looked at are the overall design of the buildings as well as recorded thermal data collected during a pilot study. The results show that the building provided an indoor environment that is cooler than the outside. Suggestions are also made to further improve the indoor thermal environment.

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Keywords: Hot-humid climate; Natural ventilation; Passive cooling

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1. Introduction

In the year 2010, Malaysia has seen an increase in energy dependency, particularly in the residential and commercial sectors. Together, these two building categories consumed more than half of the country's generated energy [1]. From this amount, the air conditioning facility in a typical household consumes approximately 21% of energy use, while electric fans use about 2% [2]. Taking into consideration the significant amount of electricity spent on cooling devices, it is possible that by reducing cooling loads in buildings via passive means, overall energy use in these sectors may be lowered as well.

One such building which belongs in the residential and/or commercial sector is the 'shophouse'. In Malaysia, it is relatively common to find shophouses, especially in the state of Penang. There are around 7000 units in this state alone [3]. Many of Penang's shophouses were built in the 19th and 20th century, corresponding with the arrival of tradesmen from Southern China [4].

On the 7th of July 2008, the city of George Town in the state of Penang, Malaysia was inscribed as a World Heritage Site by UNESCO. According to the 'outstanding universal values' (OUV) assessment, it is said that George Town represented a 'Melting Pot of Multicultural Architecture and Townscape' [5]. This reinforces Penang's status as a world-recognized place showcasing a distinct blend of influences which resulted in a large variety of architecture such as townhouses, religious buildings of different faiths, colonial public buildings and also shophouses. With the inscription also came the responsibility to conserve these centuries-old buildings, located within the heritage site of George Town.

The heritage shophouses in Penang can be categorized either in the Early 'Penang' Style (1790s - 1850s), 'Southern Chinese' Eclectic Style (1840s - 1900s), Early 'Straits' Eclectic Style (1890s - 1910s), Late 'Straits' Eclectic Style (1910s -1940s), Art Deco Style (1930s -1960s) or Early Modernism Style (1950s -1970s). These buildings typically stand at two storeys high. The lower floor serves as commercial space for trading whereas the upper floor usually serves as the tenants' residence. Shophouses were built in rows, which formed the streets and town grid. Typical building materials found in these buildings are clay bricks, granite, plaster and timber.

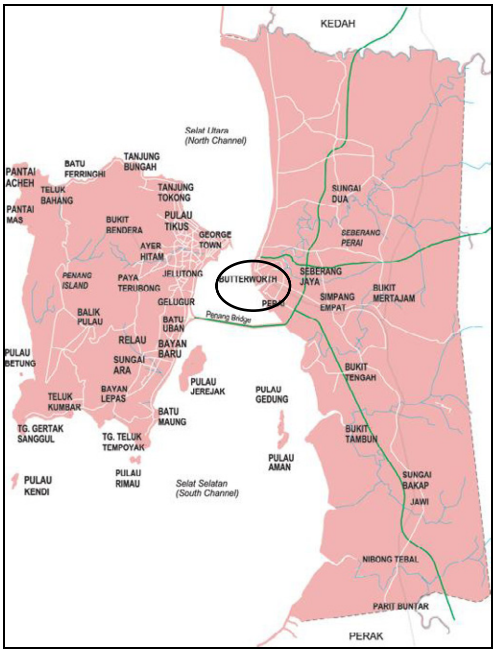
The original design of the Penang heritage shophouses is suggested to be influenced not only by the prevalent colonial and Chinese influence of the time, but also the hot and humid character of Penang's local climate [6]. Therefore, as well as having key design elements such as arches and stylized columns, most of the original shophouses have large openings, louvered doors and sheltered pedestrian walkways (also called five foot-way); all part of an integrated design which responds to the need of solar shading and passive cooling. Other features such as jack-roofs and air wells can also be found in some of the buildings.

Considering the increasingly pressing issues of energy use, environmental sustainability and also the implication that a large number of shophouses will continue to exist for many years under the protection of World Heritage Site, UNESCO, it is important for the environmental impact of these buildings to be discussed. Information of various types have resurfaced since the World Heritage Site inscription such as building catalogues and drawings, but little has been researched in regards to the claims of heritage shophouses operating on low energy and having climate-responsive characteristics [6, 7, 8].

This paper discusses the thermal performance of a heritage shophouse in Penang, Malaysia, which uses passive cooling. Unlike contemporary buildings of the same type, the heritage shophouse possesses various architectural features which would theoretically allow it to keep cool during the day. Aspects which are looked at are the overall design of the buildings as well as thermal data collected during a pilot study. The results show that the building provided an indoor environment which is cooler than the outside. Suggestions are also made to further improve the indoor thermal environment.

2. Methods

A pilot study for thermal performance was conducted on a heritage shophouse in George Town, Penang in the month of October 2010 to examine the degree of influence of the building's envelope on the indoor air temperature and humidity reduction.



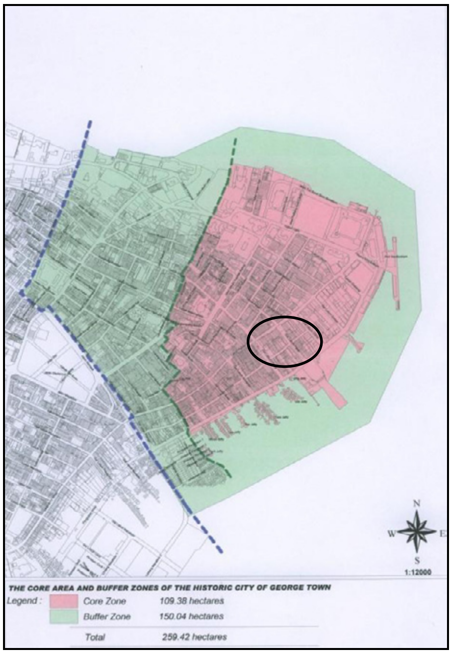


Figure 1: Penang map, Figure 2: The core zone and buffer zone of the historic city of George Town

Penang island is located off the northwest coast of peninsular Malaysia (Fig. 1). The climate in George Town, Penang, is generally hot and humid throughout the whole year. However, being on an island, the temperature within the city is often higher than on the mainland; sometimes reaching as high as 35°C during the day. Temperature ranges from 29°C to 35°C during the day and from 26°C to 29°C at night.

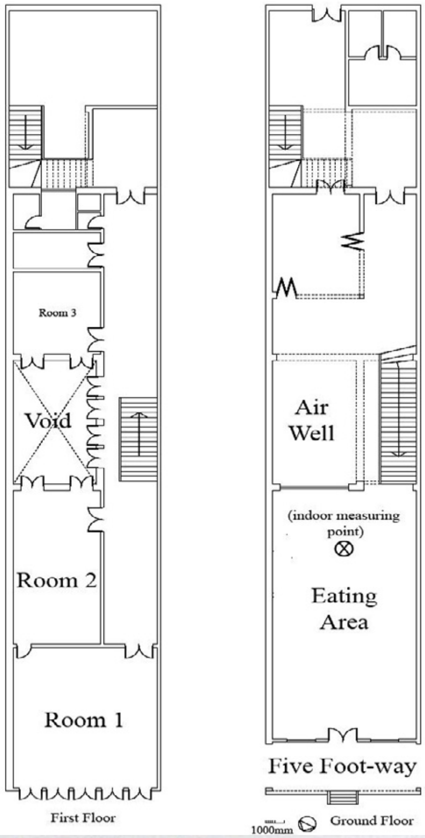
A total of 259.42 hectares (2.59 km²) of George Town was inscribed as a UNESCO World Heritage Site. The 'core zone' takes up the inner area of 109.38 hectares (1.09 km²) and the outer 'buffer zone' was allocated 150.04 hectares (1.50 km²), (Fig. 2).

The heritage shophouse chosen for this pilot study is located on Lebuh Armenian, in the core zone of the World Heritage Site.

Figure 3: View of the heritage shophouse façade

This case study involves the study of a Penang heritage shophouse; a sample of a 'Southern Chinese' Eclectic Style building [9]. This southwest-oriented building has been carefully restored and re-adapted for the use of a restaurant in the year 2005 by its owner. As is typical in Penang heritage shophouses, this unit has relatively high thermal mass as its thick walls are constructed of clay bricks. Restoration efforts in this building include the replacement of the terracotta roof tiles, the granite flooring in the air well area, iron staircase and also the wooden louvre window shutters. A few of the distinctive features of this building which may contribute to its thermal performance can be seen from its façade (Fig. 3). Chinese-styled air vents are built near the ceiling in the façade wall. The doors and windows are constructed of timber and are fitted with louvres/openings to for ventilation. The wall is constructed low on the first floor (to allow maximum ventilation via tall louvred shutters), and fitted with Chinese ceramic air vents. During the study, the shophouse was occupied by the tenants and patrons between the hours of 11am to 3pm and 6.30pm to 10pm. Mechanical ventilation was not used for the duration of study.

Measurements of the indoor thermal environment were taken in the eating area on the ground floor (Fig. 4). The floor-to-ceiling height in this area is 4.0 metres. Air temperature and relative humidity were measured and recorded at the height of 1.0 metre above floor level for the thermal environment analysis. The measurable scale for temperature is in degree Celsius and humidity, in percentage. The data logger used indoors was a SEKONIC Hygro-Thermograph (ST-50). All indoor measurements were taken in 15-minute intervals. For recording the surrounding outdoor measurements, a digital temperature probe was used.



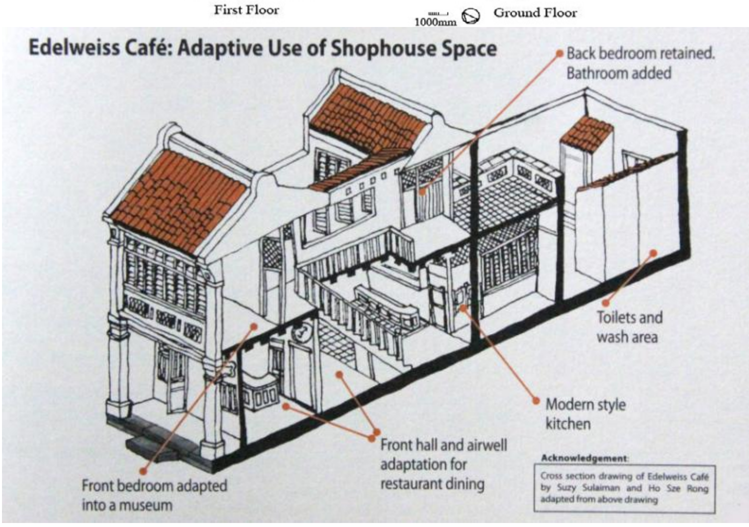


Figure 4: Floor plans of the shophouse, Figure 5: Cross section drawing of the shophouse

3. Results and Discussion

This part of the paper discusses the results of the measurements taken inside the heritage shophouse. Fig. 6 shows the measured air temperature against the corresponding outdoor readings during the three days of data collection. As shown in the figure, the temperature within the shophouse (Ti) was well-regulated, despite the fluctuations in the outdoor temperature readings (To). The daily indoor temperature readings were seen to peak late in the afternoon, which was slightly delayed when compared to the outdoor temperature readings. Fig. 7 shows that the building envelope has managed to maintain the relative humidity indoors at a lower level throughout the day. In order to further understand the thermal function of the heritage shophouse, the following part of the assessment is based on readings collected during fair weather conditions only.

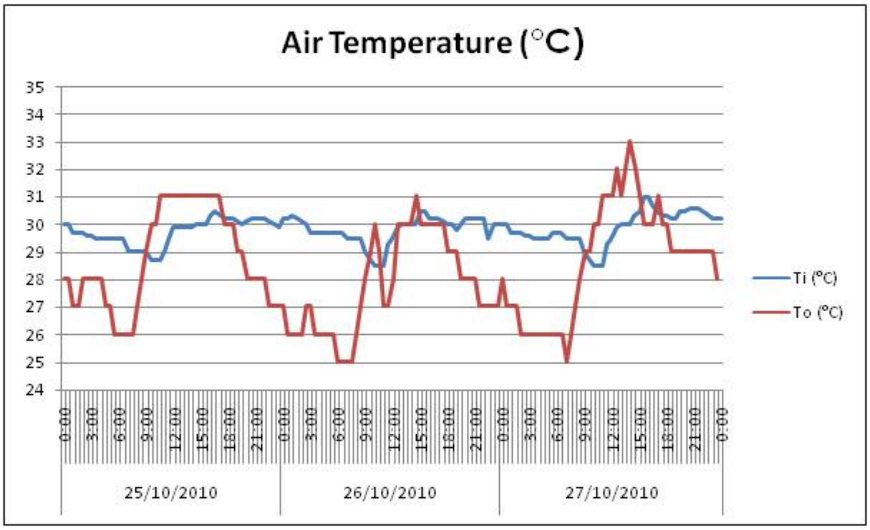


Figure 6: Air temperature results

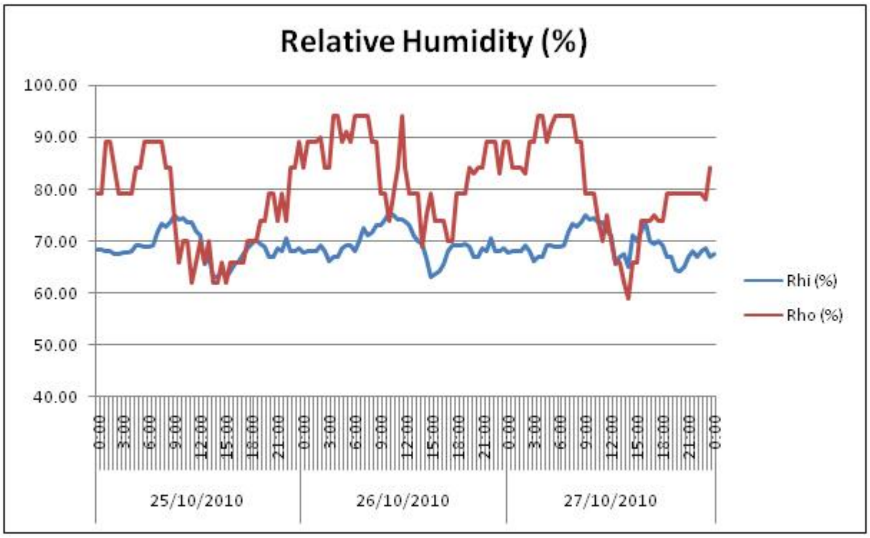


Figure 7: Relative humidity results

Fig. 8 shows the hourly mean air temperature during fair weather, without the influence of precipitation. Maximum temperatures outdoors averaged at 32°C while the minimum averaged at 25.5°C. From the figure, it can be seen that the temperature inside the shophouse has been reduced by as much as 2°C when outdoor temperature peaked. At night, the temperature was maintained with little fluctuations in its pattern. This is probably caused by heat radiating inwards from the walls which has high thermal mass. Relative humidity indoors was kept to a considerably stable level of 62% to 75% (Fig. 9). Early in the morning when outdoor humidity was highest, the indoor humidity read 23% lower and during the drier afternoon hours, relative humidity maintained at a constant level. Humidity level in masonry buildings such as the shophouse are regulated by the walls which absorbs moisture in its pores [10].

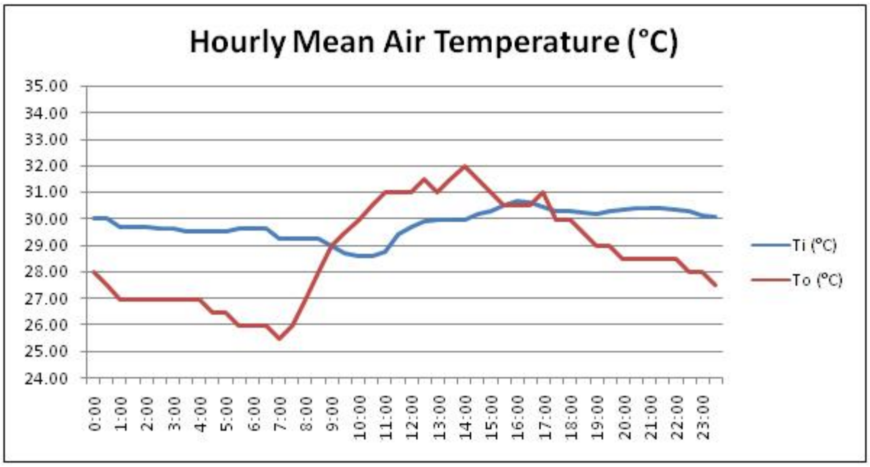


Figure 8: Hourly mean air temperature results

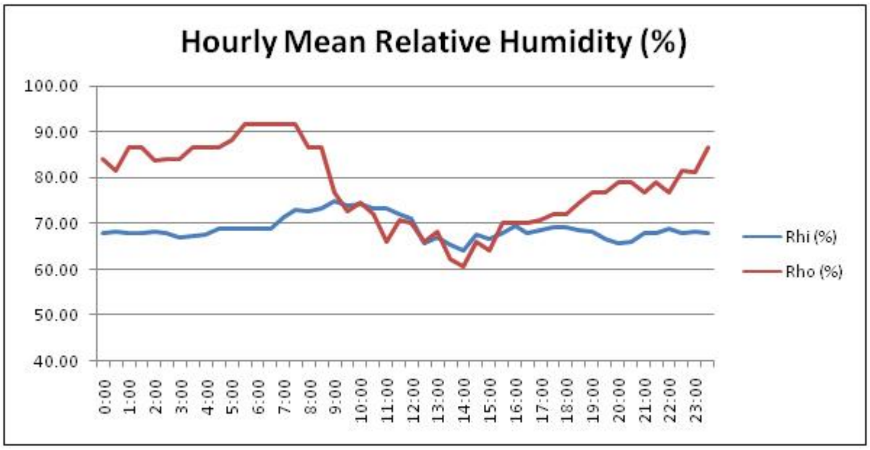


Figure 9: Mean hourly relative humidity results

In order to establish appropriate thermal conditions in buildings, practitioners often refer to the ASHRAE (American Society of Heating Refrigerating and Air Conditioning) Standard 55, which provides thermal ranges in which majority of occupants in a particular space would find comfortable. The suggested temperature range given for hot (summer) conditions is between 23°C to 26°C [11].

Table 1: Thermal comfort conditions

Figure 2: Thermal Comfort Conditions - ASHRAE *Standard 55* (1992)

Season	Optimum Temperature[a]	Acceptable Temperature Range[a]	Assumptions for other PMV inputs[b]
winter	22°C	20-23°C	relative humidity: 50% mean relative velocity: < 0.15 m/s mean radiant temperature: equal to air temperature metabolic rate: 1.2 met clothing insulation: 0.9 clo
summer	24.5°C	23-26°C	relative humidity: 50% mean relative velocity: < 0.15 m/s mean radiant temperature: equal to air temperature metabolic rate: 1.2 met clothing insulation: 0.5 clo

a: refers to operative temperature, defined as *"the uniform temperature of an imaginary black enclosure in which an occupant would exchange the same amount of heat by radiation plus convection as in the actual nonuniform environment. Operative temperature [t_o] is numerically the average of the air temperature (t_a) and mean radiant temperature ($\bar{t}_r$), weighted by their respective heat transfer coefficients (h_c and h_r):* (ASHRAE *Standard 55*, 1992, p.4)

$$t_o = (h_c t_a + h_r \bar{t}_r)/(h_c + h_r)$$ "

b: if the value of these assumptions differs, refer to comfort zone diagrams and tables given in ASHRAE *Standard 55*, for appropriate temperature ranges.

(Source: ASHRAE Standards 55, 1992)

However, research has shown that preferred indoor temperatures may differ between individuals by at least 1°C [12]. One other study suggests that Malaysians prefer the neutral temperature of 28.7°C which opens up to the possibility of the acclimatization factor being involved [13]. This would mean that locals who are brought up in Malaysia would be able to tolerate the year-long hot and humid weather which, for some people, might be uncomfortable.

The temperature readings found in the Penang heritage shophouse is slightly higher than those suggested in these studies [13]. However, if consideration is given to the varying indoor temperatures preferred among individuals [12], the degree of discomfort which may be experienced by the shophouse's occupants could be overestimated, as some would have higher tolerance to the slightly higher temperatures in Penang.

Relative humidity is suggested to be kept within 30% to 60%, according to ASHRAE guidelines. However, due to the building being naturally ventilated, the Penang heritage shophouse can only maintain relative humidity within the range of 64% to 75%; achieved with the construction of its thick brick walls [10]. Measures would have to be taken to reduce the humidity levels even further.

The main contributing factor that may have affected the reduced peak temperature within the Penang heritage shophouse is its 4 metre high ceiling on the lower level. Compared to a contemporary terrace house, the heritage shophouse's ceiling is higher by at least 1 metre. This allows stack ventilation to occur more efficiently. The process involves low-density warm air to rise and exit through openings located high in the façade walls. Cool air then infiltrates via its multiple low-positioned openings, to occupy the low-pressure space created by the exited warm air [14]. Paired with the air well construction in the heritage shophouse where warm air could rise to ceiling-level and escape, the cooling process may become even more efficient. However, more investigation needs to be conducted in order to further understand the relationship between the building's envelope, air movement and the resulting relative humidity before any further assumptions could be made regarding the building's overall performance.

4. Conclusions

In conclusion, the studied Penang heritage shophouse has to an extent, succeeded in regulating its indoor air temperature and reducing its peak temperature readings without the use of mechanical ventilation devices. Indoor relative humidity was also significantly moderated with significant reduction during peak readings. However, with the aid of devices such as electric fans, improved indoor thermal conditions such as increased air movement and/or lower air temperature may be achieved. The heritage shophouse must also be kept to its intended design which encourages natural ventilation, in order for it to function efficiently and minimize the building's cooling load.

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