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Comparative assessment of vernacular passive cooling techniques for improving indoor thermal comfort of modern terraced houses in hot–humid climate of Malaysia

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Abstract

The main objectives of this study were to investigate vernacular passive cooling techniques and their potential application for improving indoor thermal comfort of naturally ventilated, modern brick terraced houses in Malaysia. Field measurement was conducted in two traditional timber Malay houses and two traditional masonry Chinese shophouses to examine their indoor thermal environments. The results of the former showed that the indoor air temperatures were higher than the outdoor air temperatures by 1 °C during daytime under open window conditions and 2 °C at night under closed window conditions on average. The emphasis was on reducing the temperature of the outdoor air before entering the lightweight house for bodily cooling by cross ventilation. The outdoor air temperature at the Malay house sites was lower than that of the terraced house site by 1.7 °C on average. The results of the latter revealed that indoor air temperatures in rooms that were adjacent to small internal courtyards were lower than the immediate outdoors by about 5 °C on average at the peak period. At night, the indoor air temperatures maintained values that were similar to the outdoors. The small courtyards were effective to cool the high thermal mass structures through nocturnal ventilative and radiative cooling. When assessed using an adaptive thermal comfort equation for hot–humid climates, the periods of indoor operative temperatures exceeding the 80% comfortable upper limit in the Malay houses, Chinese shophouses, daytime ventilated and night ventilated terraced houses were 47%, 7–8%, 91% and 42%, respectively, on fair weather days. Potential passive cooling techniques for the existing terraced houses including night ventilation, roof or ceiling insulation, window and wall shading, small courtyard concept, and microclimate modification and/or urban heat island mitigation were discussed.

Keywords: Passive cooling; Vernacular architecture; Thermal comfort; Hot–humid climate

1. Introduction

Energy savings are important in the global building sector due to concerns about energy security and effects of global warming. In hot developing regions such as Southeast Asia, cooling demand in residential buildings is a major concern since it is predicted to rise sharply in the coming decades in line with rapid urbanisation and economic growth (Levine et al., 2007; Liu et al., 2010; Sivak, 2009). In Malaysia, final energy use in the residential and commercial sector has escalated more than sevenfold

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between 1980 and 2007, which was at a higher rate than the total final energy demand growth rate (Ministry of Energy, Communications and Multimedia Malaysia, 2002; Ministry of Energy, Water and Communications Malaysia, 2009). In residential buildings, the increase was largely attributed to electricity consumption for air conditioning as air conditioner ownership expanded from approximately 13,000 households in 1970 to approximately 764,000 households in 2000 (Mahlia et al., 2004; Department of Statistics Malaysia, 2005).

Passive cooling encompasses techniques for solar and heat control, heat modulation and heat dissipation using naturally driven phenomena such as natural ventilation, radiative cooling, evaporative cooling and ground cooling (Cook, 1989; Santamouris and Kolokotsa, 2013). It is useful for improving thermal comfort in low-energy buildings. Since cooling efficiency of passive techniques is closely associated with environmental conditions, local vernacular architecture has become invaluable reference in recent studies (Kimura, 1994). It is generally believed that vernacular buildings have withstood time and have been subtly crafted over generations to incorporate passive systems in response to experience of conditions and use including the local climate and human comfort needs (Oliver, 2006). Nonetheless, any passive cooling system employed in vernacular buildings is an outcome of series of trial and error usually without proper documentation. Recent researchers were hence devoted to analyse the performance of traditional techniques using scientific methods exemplified in Meir and Roaf (2006) in order to derive principles for current use (Rapoport, 2006). In-depth studies of cooling techniques of vernacular buildings remain few, including in Malaysia. Elsewhere, recent studies employed qualitative and quantitative approaches to assess multiple environmental aspects (Nguyen et al., 2011) or specific techniques (Liu et al., 2011; Ryu et al., 2009). However, studies that assess potential application of vernacular cooling techniques to modern buildings in the context of Malaysia are lacking, although hypothetical texts that suggest vernacular environmental strategies are available (Lim, 1987).

Two fine examples of Malaysian vernacular architecture are the traditional Malay house and the traditional Chinese shophouse (Chen, 1998). The traditional Malay house is known as a well-ventilated detached building of elevated timber structure usually seen in rural villages. Its common features include a large thatched roof, low walls made of lightweight materials (wood or bamboo), a raised floor, plentiful full-height operable windows with upper ventilation grilles, and abundant vegetation (ground cover and trees) in the surroundings. Many Malay houses are traditionally oriented to face Mecca for religious reasons, thus they have east–west orientation (Lim, 1987). Although most of the above features are still identifiable at present the thatch for the roofing has been replaced with modern materials such as zinc for easy maintenance and other reasons. Part of the house is also constructed using brick and cement on ground in many cases today. Hassan and Ramli (2010) conducted field measurement in a Malay house recently to analyse the performance of natural ventilation in the house during daytime (6 a.m.–6 p.m.). The study stated that indoor air temperature was higher than the outdoors in early morning and afternoon periods (Hassan and Ramli, 2010). However, night-time thermal environment was not evaluated. Its outdoor conditions are also less studied. As urban environments become hotter, studies of modifying microclimates using trees and grass were pursued as techniques to lower ambient temperatures (Bowler et al., 2010) and cool buildings better (Mochida et al., 2006).

Meanwhile, the traditional Chinese shophouse is a narrow, deep-plan brick building situated in rows in relatively dense urban areas. Chinese shophouses in Malaysia have traditionally been two storeys high, with the lower floor used for trading and the upper floor for residential purposes (Chen, 1998). Nevertheless, the living spaces above are being replaced with commercial function in modern shophouses. An important feature of the traditional Chinese shophouse is having one or more internal courtyards in each building (Chen, 1998). While courtyard houses are common worldwide, courtyards have existed in different scales and configurations across regions (Edwards et al., 2006; Knapp, 1999; Rapoport, 2007). In southern China, where the courtyards in Malaysia and other parts of Southeast Asia originated, small courtyards are most common (Knapp, 1999). Several studies have indicated that courtyard geometry influences the amount of solar radiation received and temperature in a courtyard through modelling of generic building forms. Basically, smaller and deeper courtyards are shaded better (Muhaisen, 2006; Yang et al., 2012). Nonetheless, thermal environment inside small courtyards in row buildings in hot–humid climate has not been studied in detail.

The primary objectives of this study are dual, which include:

(1) to investigate indoor thermal environments of the above-mentioned vernacular houses (traditional Malay house and traditional Chinese shophouse) and their passive cooling techniques; and
(2) to discuss potential application of the vernacular passive cooling techniques to modern urban houses for improving indoor thermal comfort in naturally ventilated condition.

The target modern houses are brick terraced houses, which form majority of the existing urban housing stock in Malaysia. The percentage of terraced houses in 2010 was 42% (Department of Statistics Malaysia, 2012). This study employs field measurement to address the first objective scientifically in Sections 2 and 3. Subsequently, the thermal performance of the vernacular houses is compared with that of existing terraced houses, which is derived from the results of a previous field experiment (Kubota et al.,