（別紙様式６）

(Attached Form 6)

学位論文の要旨（論文の内容の要旨）
Summary of the Dissertation (Summary of Dissertation Contents)

論　文　題　目
Energy-saving Modifications Through Passive Cooling for Urban Houses in Hot-humid Climate of Malaysia

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The main objective of this study is to develop comprehensive energy-saving modification techniques through passive cooling for the existing urban houses in Malaysia. Housing stocks have been increasing over the past few decades in Malaysia and reached more than 4.5 million houses at present. More than 90% of the urban houses are constructed of brick and concrete and the majority of them are terraced houses (more than 40%). These brick modern houses became the norm all cross the Southeast Asian region despite its hot-humid climate, but its energy-saving measures has not been studied sufficiently. Meanwhile, growing energy consumption for space cooling in buildings become a major concern in this region. The findings of this study are expected to provide practical guidelines of energy-saving modifications for the modern brick houses to reduce its energy consumption for cooling thus anthropogenic heat release as well as resultant CO2 emissions, while achieving indoor thermal comfort.

The thesis is composed of eight chapters. After giving the introduction (CH. 1) and the literature review (Ch. 2), the results of field measurements conducted in traditional courtyard houses are presented in Ch. 3. The objective was to identify the thermal functions of internal courtyards in traditional CSHs located in the hot-humid climate of Malaysia. The aim is to provide useful passive cooling strategies for modern urban houses. Field measurement was conducted in several Chinese Shophouses (CSHs) with courtyard in Malacca, Malaysia in 2014 for the data collection. The first analysis investigates the effects of courtyard form on indoor thermal environment in the CSHs. Statistical analysis was applied to find the effects of the measured parameters to the indoor thermal environment in the CSHs especially in the courtyard. As a result, it was found that the daily maximum air temperature in internal courtyards can be explained using the sky view factor (SVF) and the height of the courtyard. In contrast, the daily minimum air temperature is determined by the difference in the heights of the building and walls that form the courtyard. Meanwhile the key parameter that affecting the absolute humidity in the courtyard is the ratio of the courtyard area to the entire building area. As for relative humidity, the parameter that affecting the maximum value is the difference in the heights of a courtyard, while the height of the courtyard and the opening area of the courtyard influenced the its minimum value. The courtyard forms that characterized their thermal environments were classified into five types. Secondly, detailed comparison between two CSHs with different courtyard forms were conducted. This analysis was based on the data of intensive field measurement in both CSHs. It was found that the different types of courtyards performed different functions with respect to improving the indoor thermal comfort in the adjacent living halls. The results showed that shades courtyard with cross-ventilation during daytime would enhance the thermal comfort in the indoor condition especially in the living hall of the CSHs. The results also give an insight that there are mainly two different cooling strategies in achieving indoor thermal comfort through natural ventilation in the tropics, i.e. comfort ventilation and structural cooling.

Ch. 4 explains the experimental houses, which were constructed in the campus of a Malaysian university. The experimental houses were designed to represent the typical two-storey terraced house in Malaysia. Brief experiment has been conducted to investigate the effects of the end wall insulation under night-time and day-time ventilation. The results showed that the average air temperature and the surface temperature in the master bedroom of both house were almost similar under night-time and daytime ventilation condition. This indicates

that the external wall insulation successfully eliminates the thermal effects from the surrounding. Therefore, fair comparison between the results in both houses can be obtained.

The result of numerical simulations to find optimum combinations of modification techniques are summarized in CH. 5. The simulation was conducted using TRNSYS and COMIS program. The statistical analysis of Design of Experiment (DOE) was employed to simplify the number of study cases for the simulation in order to find the optimum combinations of modification techniques. In addition, special attention was given to the effects of the techniques on the thermal environment in the master bedroom and the living room spaces to obtain the optimum combinations. As a result, the proposed modifications include roof insulation, external wall outside insulation, external shading, and whole house ventilation.

The result of full-scale measurements to confirm the effects of the proposed modification are shown in Ch. 6. It was found that, the application of proposed modifications, i.e. roof insulation, external wall insulation, external shading and whole house ventilation successfully reduced indoor air temperatures by about 0.8°C during the day and night under the structural cooling strategy. In the case of comfort ventilation strategy, the temperature reduction during the night-time is about 0.7°C while only small reduction observed in the daytime. Nevertheless, the whole house ventilation was not able to reduce the nocturnal indoor air temperatures as low as outdoor in both cooling strategies. Ventilation through the slit window provided slightly larger reduction of indoor air temperature in the master bedrooms at night. It was also seen that the surface temperatures of inner walls, especially the ceiling, was cooler by up to 1.7°C when the slit windows were opened instead of the main windows at night. The resultant indoor thermal comfort of two different cooling strategies, i.e., structural cooling and comfort ventilation was evaluated by using operative temperature (OT) and SET*. Based on the results of OT in the master bedroom and living hall in structural cooling showed lower values than those of comfort ventilation. However, the SET* of these spaces in both cooling strategies was almost the same during the daytime (approximately 30.0°C and 30.3°C SET*).

The specific modification techniques in different two cooling strategies are discussed in the following chapter, i.e. Ch. 7. It was found that the cooling strategy of comfort ventilation is probably preferable than that by the structural cooling for the hot-humid climate of Malaysia. This is due to the effect of lower indoor humidity level and relatively high indoor wind speed can offset the effect of air temperature reduction obtained by structural cooling during daytime. The application of roof insulation, external (outside surface) insulation and external window shading successfully reduced the daytime air temperature in the master bedroom and the living hall. Meanwhile, the application of whole house ventilation is effective in providing lower nocturnal indoor air temperature in the respective indoor spaces (i.e. master bedroom and the living hall) compared to the master bedroom and attic ventilation. As a final result, the comfort ventilation strategy with other passive cooling modifications (i.e., roof insulation, external shading and whole house ventilation) is recommended for urban houses in the hot-humid climate.

Ch. 8 summarizes the key findings from the respective chapters as conclusion, followed by the discussion on future studies.