

EFFECTIVENESS OF PASSIVE COOLING STRATEGIES OF INDOOR
THERMAL CONDITIONS FOR TERRACE HOUSE UNDER HOT AND HUMID
CLIMATE

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DEDICATION

This thesis is dedicated to my parents, who gave me the breath to open my mind and soul of knowledge.

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I started this research five years ago at the age of 48, with very limited knowledge in research. From excitement to lost and back to hope, I wish to express my sincere appreciation and thanks to my research supervisor, Assoc. Prof. Dr. Sheikh Ahmad Zaki bin Shaikh Salim, for his encouragement, guidance, critics and friendship. Without him, I won't be able to complete my research and writing this thesis. I am also very thankful to Professor Dr. Aya Hagishima from Kyushu University, Japan, Professor Dr. Hom Bahadur Rijal from Tokyo City University, Yokohama, Japan, and Dr. Mohd Azuan Zakaria from Universiti Tun Hussein Onn Malaysia, Johor, Malaysia for their guidance, advices and motivation. Without their continued support and interest, this thesis would not have been the same as presented here.

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ABSTRACT

Global warming has caused the air temperature to increase and this has a serious impact on the urban area whereby causing heat wave during the summer in temperate climate area and all year long in tropical region. In Malaysia, heat wave has caused residential buildings especially terrace houses in urban areas to experience thermal discomfort. Passive cooling strategies such as natural ventilation and building retrofit method is proven to be a more effective method to resolve thermal discomfort. Therefore, the objective of this study is to assess the performance of passive cooling with different natural ventilation and building retrofit methods on improving the indoor thermal conditions for terrace house in hot and humid climate conditions. The performance of each method was assessed based on the estimated operative temperature (T_{op}) in the building and compared with American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 55, European Standard EN15251, and adaptive thermal comfort equation (ACE) developed from ASHRAE RP-884 database for hot and humid climate. The field measurement to measure the thermal conditions of the house was conducted in two stages in a corner terrace house located in Kuala Lumpur, Malaysia. Climatic data that influenced the T_{op} , such as outdoor and indoor air temperature, relative humidity, outdoor wind velocity, indoor air velocity, indoor globe temperature, and outdoor solar radiation were measured. In the first stage, four types of natural ventilation which were full day ventilation (FV), full day no ventilation (WV), day ventilation (DV), and night ventilation (NV) were adopted to evaluate the performance of different natural ventilation strategies. The measurement was conducted in all rooms on the first floor. In the latter stage, the measurement was carried out in the master bedroom located on the first floor due to its west facing orientation and it being the hottest part in the investigated house. A study of four approaches on natural ventilation combined with different building retrofit methods which are high density polyethylene (HDPE) nets as roof cover, heat insulation above ceiling, and active cooling method with ceiling fan were conducted to analyse how each combination of methods assist in the thermal performance of the room. The results from the first stage showed that the mean indoor temperature under natural ventilation was approximately 27–37 °C, and FV and DV recorded better correlation between outdoor and indoor temperature compared with WV and NV. Although natural ventilation could improve the thermal condition in the room, but it was still not enough to achieve the acceptable indoor thermal condition under relevant international standards. The use of roof cover in the second stage reduced convective heat flux of approximately 70–80% in the attic and 88% in the room. Meanwhile, the mean of daytime air temperature in the room was reduced approximately 1°C. However, the heat insulation layer above the ceiling did not contribute much in improving thermal condition of the room during daytime. Whereas the thermal condition in the room became worse during night time due to the heat trapped by this heat insulation layer. As a conclusion, a roof cover with HDPE nets managed to improve the compliance on ACE hot and humid climate from 38% with only natural ventilation to 48% after a roof cover was added on the roof. Due to the effectiveness of improving the thermal condition in the house, this passive cooling method employing a roof cover with HDPE nets has the potential for further research and to be developed as a passive building retrofit method for low-cost landed houses with roof tiles in Southeast Asia such as in Indonesia and Thailand.

ABSTRAK

Pemanasan global telah menyebabkan suhu udara bertambah di kawasan bandar dan memberi kesan yang serius melalui gelombang haba semasa musim panas di kawasan iklim empat musim dan sepanjang tahun di kawasan tropika. Di Malaysia, gelombang haba telah menyebabkan bangunan kediaman terutamanya rumah teres di kawasan bandar menghadapi ketidakselesaan haba. Strategi penyejukan pasif, seperti kaedah pengudaraan semula jadi dan pengubahsuaian bangunan telah terbukti sebagai kaedah yang lebih berkesan untuk menyelesaikan ketidakselesaan haba. Oleh itu, tujuan penyelidikan ini adalah untuk menilai pencapaian strategi penyejukan pasif dengan beberapa kaedah pengudaraan semula jadi dan kaedah pengubahsuaian bangunan bagi rumah teres di kawasan iklim panas dan lembab. Pencapaian setiap kaedah dinilai berasaskan suhu pengendalian (T_{op}) dalam bangunan dan dibandingkan dengan *American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 55*, *European Standard EN15251*, dan persamaan keselesaan haba penyesuaian (ACE) dibangunkan daripada pangkalan data *ASHRAE RP-884* untuk iklim panas dan lembab. Pengukuran keadaan haba dijalankan dalam dua peringkat di sebuah rumah teres lot tepi terletak di Kuala Lumpur, Malaysia. Data cuaca yang mempengaruhi T_{op} , seperti suhu udara, kelembapan relatif dalaman dan luaran, kelajuan angin luaran dan udara dalaman, suhu globe dan sinaran matahari telah diukur. Pada peringkat pertama, empat kes pengudaraan semula jadi telah dikaji, iaitu pengudaraan sepanjang hari (FV), tanpa pengudaraan sepanjang hari (WV), pengudaraan waktu siang (DV), dan pengudaraan pada waktu malam (NV). Pengukuran telah dijalankan dalam semua bilik di tingkat atas rumah. Pada peringkat kedua, pengukuran hanya dijalankan dalam bilik tidur utama di tingkat atas, dengan alasan bahawa bilik itu menghadap arah barat dan merupakan bilik yang paling panas dalam bangunan itu. Empat kaedah penyelidikan dengan pengudaraan semula jadi digabungkan dengan pelbagai kaedah pengubahsuaian bangunan, iaitu penutup bumbung dengan jaring polyethylene (HDPE) ketumpatan tinggi, penebat haba atas siling, dan cara penyejukan aktif dengan kipas siling telah digunakan untuk mengkaji bagaimana setiap kaedah gabungan dapat memperbaiki prestasi haba dalam bilik. Dapatan kajian daripada peringkat pertama menunjukkan purata suhu dalam bilik di bawah kaedah pengudaraan semula jadi adalah kira-kira 27–37 °C, dan FV dan DV menunjukkan korelasi yang lebih baik antara suhu dalaman dengan luaran dibandingkan dengan WV dan NV. Sungguhpun pengudaraan semula jadi boleh memperbaiki keadaan haba dalam bilik, namun tidak mencukupi untuk mencapai keperluan keadaan haba dalaman di bawah piawaian antarabangsa berkenaan. Penggunaan penutup bumbung pada peringkat kedua dapat mengurangkan fluks haba konveksi sebanyak 70–80% di dalam loteng dan 88% di dalam bilik. Pada masa yang sama, purata suhu udara dalam bilik pada waktu siang telah dikurangkan kira-kira 1°C. Penambahan lapisan penebat haba di atas siling bukan sahaja tidak dapat menyumbang kepada pembaikan keadaan haba dalam bilik pada waktu siang, bahkan keadaan haba dalam bilik menjadi lebih teruk pada waktu malam disebabkan oleh pemerangkapan haba oleh lapisan penebatan haba ini. Apabila keputusan penyelidikan dibandingkan dengan penutup bumbung dengan jaring HDPE dapat memperbaiki pematuhan kepada ACE iklim panas dan lembab, daripada 38% dengan pengudaraan semula jadi sahaja kepada 48% selepas penutup bumbung ditambah di atas bumbung. Disebabkan kecekapan peningkatan keselesaan haba dalam rumah, dan kaedah yang senang untuk membina penutup bumbung dengan jaring HDPE, kaedah penyejukan pasif ini mempunyai potensi untuk penyelidikan masa depan dan dibangunkan sebagai kaedah pengubahsuaian pasif untuk rumah kos rendah dengan atap bumbung di Asia Tenggara, seperti di Indonesia dan Thailand.

TABLE OF CONTENTS

	TITLE	PAGE
	DECLARATION	iii
	DEDICATION	iv
	ACKNOWLEDGEMENT	v
	ABSTRACT	vi
	ABSTRAK	vii
	TABLE OF CONTENTS	viii
	LIST OF TABLES	xiii
	LIST OF FIGURES	xv
	LIST OF ABBREVIATIONS	xxii
	LIST OF SYMBOLS	xxiii
	LIST OF APPENDICES	xxv
CHAPTER 1	INTRODUCTION	1
	1.1 Research Background	1
	1.2 Problem Statement	4
	1.3 Research Questions	6
	1.4 Research Objectives	6
	1.5 Research Scope	7
	1.6 Significance of Research	7
	1.7 Organization of Thesis	8
CHAPTER 2	LITERATURE REVIEW	11
	2.1 Background	11
	2.2 Passive Cooling in Residential Building of Hot Humid Climate	11
	2.3 Ventilation	33
	2.3.1 Natural Ventilation	33
	2.3.2 Cross Ventilation	34
	2.3.3 Stack Effect Ventilation	38

2.3.4	Mechanical Ventilation	40
2.3.5	Attic Ventilation with Turbine Ventilator	40
2.3.6	Wind Catcher	41
2.4	Building Retrofitting	41
2.4.1	Shading Device on External Wall	42
2.4.2	Heat Insulation on External Wall	43
2.4.3	Double Glazing Windows	44
2.4.4	Retro-Reflective Film on Windows	44
2.4.5	Heat Insulation on Roof	46
2.4.6	Cool Roof	47
2.4.7	Color of Roof	49
2.4.8	Roof Shading with Roof Cover	49
2.5	Gap of Research	51
CHAPTER 3	RESEARCH METHODOLOGY	55
3.1	Background	55
3.1.1	Process of Research	55
3.2	Selection of Residential Building	58
3.2.1	Location	58
3.2.2	Climatic and Meteorological Conditions	60
3.2.3	Characteristics of the House	60
3.3	Field Measurements	65
3.3.1	Instruments for Measurement	66
3.3.2	Stage 1 – Passive Cooling with Natural Ventilation Strategies	71
3.3.2.1	Experimental Setup for Stage 1	72
3.3.2.2	Setup of Local Weather Station	75
3.3.3	Stage 2 - Building Retrofitting Methods	79
3.3.3.1	Experimental Setup for Stage 2	81
3.3.3.2	Retrofitting by Using Roof Cover	84
3.3.3.3	Retrofitting of Insulation Above Ceiling	86

	3.3.3.4	Mechanical Ventilation with Ceiling Fan	87
3.4		Consistency Check on Instruments	88
	3.4.1	Air Temperature Measurement Instruments	88
	3.4.2	Relative Humidity Sensors	90
	3.4.3	Air Velocity Sensors	91
	3.4.4	Outdoor Air Temperature Sensors	93
	3.4.5	Air Change Rate of the Rooms	95
	3.4.6	Methods of Measurement and Data Analysis	99
	3.4.7	Comparison of Acceptable Indoor Thermal Conditions with Related Standards	99
	3.4.7.1	ASHRAE Standard 55	99
	3.4.7.2	European Standard EN15251	100
	3.4.7.3	Adaptive Comfort Equation for Hot and Humid Climate	100
	3.4.8	Estimation of Operative Temperature using Climatic Data	100
	3.4.8.1	Mean Radiant Temperature	101
	3.4.8.2	Operative Temperature	101
	3.4.8.3	Absolute Humidity	101
	3.4.8.4	Determination of Fair Day and Rainfall Day	102
	3.4.9	Measurement on Effectiveness of Building Retrofitting Methods	103
	3.4.9.1	Decrement Factor	103
	3.4.9.2	Convective Heat Transfer	103
	3.4.9.3	Equivalent Outdoor Temperature	104
3.5		Summary	105
CHAPTER 4		EVALUATION ON THE PERFORMANCE OF PASSIVE COOLING WITH DIFFERENT NATURAL VENTILATION MODES FOR TERRACE HOUSE UNDER HOT HUMID CLIMATE	107
4.1		Background	107

4.2	Outdoor Thermal Conditions	107
4.2.1	Air Temperature	108
4.2.2	Relative Humidity	109
4.2.3	Wind Speed	111
4.2.4	Solar Radiation	112
4.3	Indoor Thermal Conditions	113
4.3.1	Air Temperature	114
4.3.2	Globe Temperature	118
4.3.3	Relative Humidity	120
4.3.4	Air Velocity	122
4.4	Analysis on Different Ventilation Modes Affect the Influence of Outdoor Air Temperature to Indoor Air Temperature	124
4.5	Differences Between Indoor and Outdoor Air Temperatures	132
4.6	Vertical Indoor Air Temperature under Natural Ventilation and Mixed Mode Ventilation	136
4.7	Influence of Surface Temperature on Indoor Air Temperature	139
4.8	Summary	142
CHAPTER 5	ASSESSMENT ON THE PERFORMANCE OF PASSIVE COOLING WITH DIFFERENT BUILDING RETROFITTING METHODS FOR TERRACE HOUSE UNDER HOT HUMID CLIMATE	145
5.1	Background	145
5.2	Outdoor Climatic Environments	146
5.2.1	Air Temperature	147
5.2.2	Relative Humidity	148
5.2.3	Wind Speed	149
5.2.4	Solar Radiation	151
5.3	Indoor Climatic Environments	152
5.3.1	Air Temperature	153
5.3.2	Globe Temperature	154
5.3.3	Relative Humidity	155

5.3.4	Air Velocity	156
5.4	Relationship Between Indoor and Outdoor Air Temperature	158
5.5	Comparison Between Indoor and Outdoor Climatic Environment	159
5.6	Comparison on Vertical Temperature Profile under different Building Retrofitting Methods	161
5.7	Effect of Roof Cover on Indoor Thermal Environments	163
5.7.1	Temperature Difference between Roof Surface and Outdoor Air	164
5.7.2	Convective Heat Transfer through The Attic	165
5.7.3	Equivalent Outdoor Temperature	167
5.8	Summary	171
CHAPTER 6	ANALYSIS ON THE INDOOR COMFORT LEVEL OF THE PROPOSED PASSIVE COOLING STRATEGIES BASED ON ADAPTIVE COMFORT STANDARDS	173
6.1	Background	173
6.2	Comparison on Performance of Operative Temperature with Different Natural Ventilation Strategies	173
6.3	Comparison on Performance of Operative Temperature with Different Building Retrofitting Method	178
6.4	Summary	182
CHAPTER 7	CONCLUSIONS	185
7.1	Background	185
7.2	Research Outcomes	185
7.3	Contributions to Knowledge	187
7.4	Future Works	187
REFERENCES		189
LIST OF PUBLICATIONS		265

LIST OF TABLES

TABLE NO.	TITLE	PAGE
Table 2.1	Summary of literatures reviewed on passive cooling in residential buildings from 2007 to 2019	17
Table 2.2	Approaches of heat removing methods through ventilation on residential building from 2007 to 2019	24
Table 2.3	Approaches of heat preventive methods on residential building from 2007 to 2019	29
Table 3.1	Detail information of investigated house	64
Table 3.2	Building materials of investigated house	65
Table 3.3	List of instruments used for indoor measurement	67
Table 3.4	List of instruments used for outdoor measurement	69
Table 3.5	Details of ventilation modes and strategies	72
Table 3.6	Details of four cases of study on building retrofitting method	81
Table 3.7	Coefficient of determination, R^2 for HOBO thermo recorders in relation to thermocouple connected to channel 1 of Graphtec GL820	90
Table 3.8	Coefficient of determination, R^2 for HOBO thermo recorders in relation to Assmann	91
Table 3.9	Average ACH of investigated rooms	98
Table 4.1	Stage 1 – statistical data of outdoor climatic environments	108
Table 4.2	Stage 1 – statistical data of indoor climatic environments	113
Table 4.3	Indoor air temperature at various height across four natural and mixed mode ventilation strategies	137
Table 5.1	Stage 2 – statistical data of outdoor climatic environments	147
Table 5.2	Average hourly solar radiation in a day and daily average of outdoor air temperature for four building retrofitting methods in stage 2	152
Table 5.3	Stage 2 – statistical data of indoor climatic conditions	153
Table 5.4	Summary of convection heat flux against solar radiation for four approaches in the attic and master bedroom	170

Table 6.1	Average climatic parameter values in all rooms and ventilation modes	174
Table 6.2	Percentage of compliance T_{op} under different natural ventilation strategies with T_{comfop} under ASHRAE Standard 55, EN15251 and ACE hot and humid	175
Table 6.3	Percentage of compliance of mean T_{op} in different room and area for all natural ventilation strategies with T_{comfop} under ACE hot-humid	176
Table 6.4	Percentage of compliance T_{op} under different combination of natural, building retrofitting and active cooling methods with neutral comfortable temperatures (T_{comfop}) under ASHRAE Standard 55, EN15251 and ACE hot and humid	178

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
Figure 2.1	Regional warming in the decade 2006 to 2015 relative to preindustrial period	12
Figure 2.2	(a) Growth of global population, and (b) potential of urban heat island during night time [3]	13
Figure 2.3	Concepts of cross ventilation: (a) cross ventilation through the rooms [78], (b) fresh air move through a building when high and low pressure zones created by wind [13], and (c) type of window openings on wall to create cross ventilation [77]	35
Figure 2.4	Traditional malay house in Penang [63]	37
Figure 2.5	Diagram of stack effect ventilation [80]	38
Figure 2.6	Schematic image of reflection at building façade [72]	45
Figure 2.7	Schematics of retro-reflective film [92]	46
Figure 2.8	Picture of the three test huts [47]	47
Figure 2.9	Rooftop surface temperature images acquired by UAV-based thermal infrared camera [74]	49
Figure 3.1	Flow chart on overall process of research	57
Figure 3.2	Location of the investigated house from Google Maps in 2019: (a) location of Taman Melati in Kuala Lumpur, (b) location of investigated house in Taman Melati, and (c) the surrounding of the investigated corner unit terrace house	59
Figure 3.3	Annual variation in monthly mean outdoor air temperature and relative humidity obtained from weather station located at Universiti Teknologi Malaysia in Kuala Lumpur, Malaysia. Error bars indicated standard deviation of climatic data in each month	60
Figure 3.4	Site plan of the investigated house	61
Figure 3.5	Floor plan of the investigated house: (a) ground floor, and (b) first floor	62
Figure 3.6	Schematic views of the investigated house: (a) front view, and (b) side view	63
Figure 3.7	Measurement locations in the investigated house: a) ground floor and b) first floor	73

Figure 3.8	Indoor measurement setup. a) Thermo recorders, hot-wire anemometer, and b) thermocouple wire type k at the roof attic	74
Figure 3.9	Indoor measurement setup of thermocouple wire type k at the a) top and bottom of ceiling and b) external and internal surface of wall	75
Figure 3.10	Equipment setup for outdoor measurement. a) Thermo recorders and pyranometer; b) ultrasonic anemometer	76
Figure 3.11	The fan aspirated solar shield was protected with aluminium foil while fixed on the weather station	76
Figure 3.12	Layout of target house with surrounding building. Solid red circle refers to the location of the weather station (Microsoft Maps, 2019)	77
Figure 3.13	Hourly mean wind speed and direction from 15 February 2018 to 11 March 2018 measured at (a) local weather station and (b) Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia weather station [111]	78
Figure 3.14	Comparison of daily mean air temperature from 15 February 2018 to 11 March 2018 between local weather station and weather station at Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia	79
Figure 3.15	Measurement setup in master bedroom and attic above the room across four cases of study: (a) points of measurement in master bedroom, (b) cross section through master bedroom and roof to indicate points of measurement vertically from floor up to roof. Note: T_i : indoor air temperature, T_{csb} : ceiling bottom surface temperature, T_{cst} : ceiling top surface temperature, T_r : attic air temperature, T_{rsb} : roof bottom surface temperature, T_{rst} : roof top surface temperature	82
Figure 3.16	Setup of equipment for indoor measurement: thermocouple wire type k at top and bottom surface of roof tile	83
Figure 3.17	Setup of equipment for indoor measurement: thermocouple wire type k at top and bottom surface of ceiling	83
Figure 3.18	Setup of equipment for indoor measurement: thermocouple wire type k at outer and inner surface of wall	84
Figure 3.19	Diagrammatic description on installation of roof cover on the existing roof and setup of measurements	85
Figure 3.20	Setup on measurement of surface temperature on top surface of roof tile and air temperature between roof cover and roof	86

Figure 3.21	Installation of roof cover on the existing roof and setup of measurements: (a) existing roof covered with HDPE roof cover, (b) point of measurement for uncovered roof tiles at neighbour's house	86
Figure 3.22	Installation of rockwool slab above ceiling: (a) setup of measurement in the roof, (b) 50 mm thick rockwool slab, and (c) rockwool slab installed above ceiling boards	87
Figure 3.23	Setup on approach FV-R-C-F: (a) ceiling fan located at the center of the master bedroom, (b) the speed of the fan was set as two (approximately 175 RPM)	88
Figure 3.24	Consistency checking of air temperature sensors	89
Figure 3.25	Comparison of air temperature sensor with the reference sensor	90
Figure 3.26	Consistency checking of relative humidity sensors with digital Assmann ventilation psychrometer	91
Figure 3.27	Comparison of relative humidity sensor (Hobo) with the reference sensor (Assmann)	91
Figure 3.28	Consistency check on air velocity sensors using hand made mini wind tunnel	92
Figure 3.29	Consistency checking on air velocity sensors	93
Figure 3.30	Construction of the fan aspirated solar shield	94
Figure 3.31	Consistency checking on fan aspirated solar shields	94
Figure 3.32	Comparison between 7 solar shields on the measured outdoor air temperature	95
Figure 3.33	Equipment setup for CO ₂ concentration measurements. a) Indoor and b) Outdoor. c) Position of measurements in each bedroom	96
Figure 3.34	CO ₂ concentration against time for measurement 1 and 2 in (a) master bedroom, (b) bedroom 2, (c) bedroom 3	97
Figure 3.35	Non-linear regression of the ACH against time for measurement 1 and 2 in (a) master bedroom, (b) bedroom 2, (c) bedroom 3. Note: T: time	98
Figure 4.1	(a) Outdoor air temperature (T_o) variations, and (b) Frequency distribution of T_o for stage 1 measurements. Note: Duration of measurement is from 15 February to 11 March 2018	109

Figure 4.2	(a) Outdoor relative humidity (RH_o) variations, and (b) Frequency distribution of RH_o for stage 1 measurements. Note: Duration of measurement is from 15 February to 11 March 2018	110
Figure 4.3	(a) Outdoor wind speed (V_o) variations, and (b) Frequency distribution of V_o for stage 1 measurements. Note: Duration of measurement is from 15 February to 11 March 2018	111
Figure 4.4	(a) Solar radiation (SR) variations, and (b) Frequency distribution of SR for stage 1 measurements. Note: Duration of measurement for stage 1 (from 15 February to 11 March 2018)	112
Figure 4.5	(a) Indoor air temperature (T_i) variations, (b) frequency distribution of T_i at first floor, and (c) frequency distribution of T_i at ground floor for stage 1 measurements. Note: Duration of measurement for stage 1 (from 15 February to 11 March 2018)	117
Figure 4.6	(a) Indoor globe temperature (T_g) variations, (b) frequency distribution of T_g at first floor, and (c) frequency distribution of T_g at ground floor for stage 1 measurements. Note: Duration of measurement for stage 1 (from 15 February to 11 March 2018)	119
Figure 4.7	(a) Indoor relative humidity (RH_i) variations, (b) frequency distribution of RH_i at first floor, and (c) frequency distribution of RH_i at ground floor for stage 1 measurements. Note: Duration of measurement for stage 1 (from 15 February to 11 March 2018)	121
Figure 4.8	(a) Indoor air velocity (V_i) variations, (b) frequency distribution of V_i at first floor, and (c) frequency distribution of V_i at ground floor for stage 1 measurements	123
Figure 4.9	Regression analysis between T_i at first floor and T_o for stage 1 measurement across four natural ventilation strategies	125
Figure 4.10	Regression analysis between T_i at ground floor and T_o for stage 1 measurement across four ventilation strategies	125
Figure 4.11	Correlation between T_o and T_i for master bedroom	127
Figure 4.12	Correlation between T_o and T_i for bedroom 2	127
Figure 4.13	Correlation between T_o and T_i for bedroom 3	128
Figure 4.14	Correlation between T_o and T_i for family area	128
Figure 4.15	Correlation between T_o and T_i for bedrooms and area at first floor with strategy WV	130

Figure 4.16	Correlation between T_o and T_i for bedrooms and area at first floor with strategy FV	130
Figure 4.17	Correlation between T_o and T_i for bedrooms and area at first floor with strategy DV	131
Figure 4.18	Correlation between T_o and T_i for bedrooms and area at first floor with strategy NV	131
Figure 4.19	Variations in difference between indoor and outdoor air temperature across four ventilation strategies. Note: T_i : indoor air temperature, T_o : outdoor air temperature, WV: without ventilation, FV: full ventilation, DV: day ventilation, NV: night ventilation	133
Figure 4.20	Variation of mean difference between indoor and outdoor air temperature across four ventilation strategies for (a) daytime, and (b) night time. Note: T_i : indoor air temperature, T_o : outdoor air temperature, WV: without ventilation, FV: full ventilation, DV: day ventilation, NV: night ventilation	135
Figure 4.21	Vertical profile of average indoor T_i and outdoor T_o at three different heights across four ventilation strategies. Note: MB: master bedroom, FA: family area, B2: bedroom 2, B3: bedroom 3, LA: living area, DA: dining area, WV: without ventilation, FV: full ventilation, DV: day ventilation, NV: night ventilation	138
Figure 4.22	Comparison between T_s and T_i across four ventilation strategies. a) T_s for top and bottom surface of ceiling board and roof tile, and T_i for roof attic; b) T_s for external and internal surface of external wall, and T_i for indoor and T_o for outdoor. Note: WV: without ventilation, FV: full ventilation, DV: day ventilation, NV: night ventilation	141
Figure 5.1	(a) Outdoor air temperature (T_o) variations, and (b) Frequency distribution of T_o for stage 2 measurements. Note: Duration of measurement for stage 2 (from 3 September to 14 December 2018)	148
Figure 5.2	(a) Outdoor relative humidity (RH_o) variations, and (b) Frequency distribution of RH_o for stage 2 measurements. Note: Duration of measurement for stage 2 (from 3 September to 14 December 2018)	149
Figure 5.3	(a) Outdoor wind speed (V_o) variations, and (b) Frequency distribution of V_o for stage 2 measurements. Note: Duration of measurement for stage 2 (from 3 September to 14 December 2018)	150

Figure 5.4	(a) Solar radiation (SR) variations, and (b) Frequency distribution of SR for stage 2 measurements. Note: Duration of measurement for stage 2 (from 3 September to 14 December 2018)	151
Figure 5.5	(a) Indoor air temperature (T_i) variations, and (b) Frequency distribution of T_i for stage 2 measurements. Note: Duration of measurement for stage 2 (from 3 September to 14 December 2018)	154
Figure 5.6	(a) Indoor globe temperature (T_g) variations, and (b) Frequency distribution of T_g for stage 2 measurements. Note: Duration of measurement for stage 2 (from 3 September to 14 December 2018)	155
Figure 5.7	(a) Indoor relative humidity (RH_i) variations, and (b) Frequency distribution of RH_i for stage 2 measurements. Note: Duration of measurement for stage 2 (from 3 September to 14 December 2018)	156
Figure 5.8	(a) Indoor air velocity (V_i) variations, and (b) Frequency distribution of V_i for stage 2 measurements. Note: Duration of measurement for stage 2 (from 3 September to 14 December 2018)	157
Figure 5.9	Comparison between solar radiation (SR) in a day and decrement factor (f) on the temperature difference between air temperature in master bedroom and outdoor air temperature	158
Figure 5.10	Air temperature difference between indoor and outdoor. Note: T_i : indoor air temperature and T_o : outdoor air temperature	159
Figure 5.11	Comparison between indoor air velocity and outdoor wind speed. Note: V_i : indoor air velocity, and V_o : outdoor wind speed	161
Figure 5.12	Comparison on vertical profile of temperature differences between 0.5 m above floor and higher points of measurement above it at master bedroom across four approaches. Note: T_{rc} : surface temperature of roof cover, T_{rst} : top surface temperature of roof tile, T_{rsb} : bottom surface temperature of roof tile, T_{ag} : air temperature of air gap, T_r : air temperature in attic, T_{cst} : top surface temperature of ceiling, T_{csb} : bottom surface temperature of ceiling and T_i : indoor air temperature	163

Figure 5.13	Comparison on temperature difference between roof top surface and outdoor air on approach FV-R to show the difference between roof covered with roof cover and without roof cover. Note: T_{rst} : top surface temperature of roof tiles, T_o : outdoor air temperature, and SR : solar radiation	165
Figure 5.14	Convective heat transfer between roof tiles and attic air and between ceiling board and master bedroom air	166
Figure 5.15	Comparison on convection heat transfer (q_h) across four approaches in master room and attic	167
Figure 5.16	Comparison on convection heat flux, q_h with solar radiation, SR across four cases in (a) attic and (b) master bedroom, and comparison on q_h with equivalent outdoor temperature, T_{eff} , in (c) attic and (d) master bedroom	169
Figure 5.17	Relationship between T_i-T_o and T_{eff} . Note: T_i : indoor air temperature, T_o : outdoor air temperature, and T_{eff} : equivalent outdoor temperature	171
Figure 6.1	Operative temperatures for all rooms across four ventilation approaches compared with related international standards. Note: T_{op} : operative temperature	177
Figure 6.2	Comparison of operative temperature and outdoor air temperature with related international standard for approach full day natural ventilation (FV)	179
Figure 6.3	Comparison of operative temperature and outdoor air temperature with related international standard for approach full day natural ventilation with retrofit roof cover (FV-R)	180
Figure 6.4	Comparison of operative temperature and outdoor air temperature with related international standard for approach full day natural ventilation with roof cover and heat insulation above ceiling (FV-R-C)	181
Figure 6.5	Comparison of operative temperature and outdoor air temperature with related international standard for approach full day natural ventilation with roof cover, heat insulation above ceiling, and mechanical ventilation with ceiling fan (FV-R-C-F)	182

LIST OF ABBREVIATIONS

AC	- Air-Conditioner
ACE	- Adaptive Thermal Comfort Equation
ACH	- Air Change Rate Per Hour
ASHRAE	- American Society of Heating, Refrigerating and Air-Conditioning Engineers
CFD	- Computational Fluid Dynamics
CO ₂	- Carbon-Dioxide
DV	- Day Ventilation
FV	- Full Ventilation
FV-R	- Full Day Free Running Ventilation with Retrofit Roof Cover
FV-R-C	- Full Day Free Running Ventilation with Roof Cover and Heat Insulation Above Ceiling
FV-R-C-F	- Full Day Free Running Ventilation with Roof Cover, Heat Insulation Above Ceiling, and Mechanical Ventilation with Ceiling Fan
HDPE	- High Density Polyethylene
IPCC	- Intergovernmental Panel on Climate Change
Low-E	- Low-Emissivity
MJIIT	- Malaysia-Japan International Institute of Technology
NIR	- Near Infrared
NV	- Night Ventilation
PV	- Photovoltaic
RPM	- Round Per Minute
UHI	- Urban Heat Island
UTM	- Universiti Teknologi Malaysia
WV	- Without Ventilation

LIST OF SYMBOLS

a	-	Solar absorptivity
AH	-	Absolute humidity (g/kg _{DA})
f	-	Decrement factor
h	-	Convection heat transfer coefficient (W/m ² ·K)
q_h	-	Convective heat fluxes (W/m ²)
R^2	-	Coefficient of determination
RH_i	-	Indoor relative humidity (%)
RH_o	-	Outdoor relative humidity (%)
SR	-	Solar radiation (W/m ²)
ΔT	-	Temperature difference (°C)
T_a	-	Air temperature (°C)
T_{ag}	-	Air temperature of air gap (°C)
T_{comfop}	-	Indoor neutral comfort temperature (°C)
T_{csb}	-	Bottom surface temperature of ceiling (°C)
T_{cst}	-	Top surface temperature of ceiling (°C)
T_{eff}	-	Equivalent outdoor temperature (°C)
T_g	-	Globe temperature (°C)
T_i	-	Indoor air temperature (°C)
$T_{i,max}$	-	Maximum daily indoor air temperature (°C)
$T_{i,min}$	-	Minimum daily indoor air temperature (°C)
T_{mrt}	-	Mean radiant temperature (°C)
T_o	-	Outdoor air temperature (°C)
$T_{o,max}$	-	Maximum daily outdoor air temperature (°C)
$T_{o,min}$	-	Minimum daily outdoor air temperature (°C)
T_{op}	-	Comfort temperature (°C)
T_{outmm}	-	Daily mean outdoor air temperature (°C)
T_r	-	Attic air temperature (°C)
T_{rc}	-	Surface temperature of roof cover (°C)
T_{rsb}	-	Bottom surface temperature of roof tiles (°C)
T_{rst}	-	Top surface temperature of roof tiles (°C)

T_{wse}	-	External surface temperature of wall (°C)
T_{wsi}	-	Internal surface temperature of wall (°C)
U	-	Thermal transmittance (W/m ² ·K)
V_i	-	Indoor air velocity (m/s)
V_o	-	Outdoor wind speed (m/s)

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
Appendix A	Consistency analysis on air temperature sensors	203
Appendix B	Consistency analysis on relative humidity sensors	206
Appendix C	Calculation of air change rate	208
Appendix D	Fabrication of the fan aspirated solar radiation shield	213
Appendix E	Outdoor climatic environment in stage 1	218
Appendix F	Indoor climatic environment in stage 1	222
Appendix G	Outdoor climatic environment in stage 2	258
Appendix H	Indoor climatic environment in stage 2	261

CHAPTER 1

INTRODUCTION

1.1 Research Background

Global warming is always a main environmental issue since the industrialization era [1]. It has caused the global air temperature increased 0.85 °C from 1880 to 2012 [2]. Increase of global temperature has a serious impact to the urban area with heat wave during summer in temperate climate region and all year long in tropical region [3]. Heat wave has caused a lot of people died due to heat stroke [4], especially in urban area with high population density and limited outdoor green open space to reduce the impact of heat wave.

In hot and humid regions, such as Malaysia, the average daily air temperature is between 21 °C and 32 °C [5]. According to Malaysian Metrological Department [6], in 2019, the average temperature was 27.63 °C, and was 0.69 °C above normal temperature of 26.94 °C. Furthermore, Malaysia was hit twice by heat wave in 2019 with a recorded maximum daily temperature between 37.1 °C to 38.0 °C. This has triggered the alert level (daily maximum temperature 35 °C to 37 °C) on the temperature in the country. However, as easy solution to the critical condition of the temperature, urban dwellers will choose to stay indoors and switch on the air-conditioner (AC) system to remove heat and maintain indoor thermal environment as well as to fight the heat wave and avoid heat stroke [7, 8]. The adoption of active cooling system by using AC has caused the energy consumption increased rapidly in urban area [9]. Usage of AC is only solving the problem of heat wave, but the increase of electrical energy consumption has caused another environmental issue. Generation of electrical power will increase the emission of carbon-dioxide (CO₂) into the environment and make the global warming issue become worse [3]. This cycle of environmental problem will continue growing like a snowball and need immediate intervention to stop the cycle. A better approach to resolve the thermal issue is by using

passive cooling strategy that using minimum energy, such as natural ventilation to remove heat and heat preventive method using building retrofiting strategies to improve indoor thermal conditions and achieve thermal comfort, instead of using AC.

Indoor thermal conditions of a building are affected by the air temperature, surrounding surface temperature, humidity and air movement. American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) [10] defined thermal environment as the environment conditions that affect a person's heat loss. For a person to feel thermally comfortable, where a person is satisfied with the ambient temperature, ASHRAE [10] defined this as the condition of the mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation.

Comfortable thermal conditions can be achieved either by active or passive cooling [11]. Active cooling methods are defined as mechanical equipment to satisfy the needs of cooling within a building that not provided by nature. Active methods use electricity and heat as power source. The most used equipment in the residential buildings are fans, evaporative coolers and heat pumps [11]. Meanwhile, passive cooling in building design is an approach that managing heat gain and heat dissipation in a building in order to improve indoor thermal environment and achieve thermal comfort with low or no energy consumption [12]. They work either by removing heat from the building to a natural heat sink (sky, earth, air and water) using natural ventilation or by preventing heat from entering the building (thermal insulation and shading) from external heat sources.

Natural ventilation defined as natural forces (winds and thermal buoyancy force) due to the difference of outdoor and indoor air pressure that drive outdoor air through openings on building envelope. The openings include doors, windows, wind towers, solar chimneys and ventilators [13]. Natural ventilation utilizes onsite energy from the natural environment, combined with the passive cooling features of building components on the building envelope to remove heat from the building [13, 14].

Heat preventive methods in building design is focuses on heat gain control in a building in order to improve the indoor thermal comfort with low or no energy

consumption. Prevention of heat gains encompasses all the design techniques and building retrofitting techniques that minimizes the impact of solar heat gains through the building's envelope by installation of heat insulation layer or shading devices [12].

In comparison between active and passive cooling methods on factors of energy consumption, maintenance, retrofitting and required space, passive cooling is found to be the most suitable method for residential buildings [11]. The recommended passive cooling methods are night ventilation, controlled ventilation, shading system, roof coating, building colour and eco-evaporative cooling.

In the previous study on passive cooling [15–19], most of the studies are concentrated in temperate climate regions with moderate annual temperatures, with average monthly temperatures above 10 °C in their warmest months and above -3 °C in their colder months. However, in hot and humid climate regions with a high average daily temperature up to 21 °C to 32 °C and facing serious impact of heat wave issue, very limited studies on how passive cooling can assist in improving indoor thermal conditions can be found [7, 20]. The existing studies in hot and humid climate regions are generally on natural ventilation [7] to remove heat from the building and not on building retrofitting methods that preventing heat from entering the building.

In addition to the passive cooling methods, building types and building forms is also an important factor affecting the thermal performance of the building [21]. Terrace house formed 36.4% of total living quarters in Malaysia (*Population and Housing Census of Malaysia 2010*), and 47.8% of new launches in Malaysia (*Residential, Commercial and Industrial properties Status report 2018*). The impact of solar heat gains through building's envelope is high on terrace house with high ratio of exposure on external wall and roof to the sunlight [22]. In addition, terrace house also facing a low air velocity of 0.4-0.6 m/s as reported by Kubota and Ahmad [23]. Although terrace houses are one of the common residential building in Malaysia, however, the study is still very limited and required further exploration.

A further investigation on the effectiveness of passive cooling using different building retrofitting methods and natural ventilation strategies to the thermal

conditions of terrace houses under hot and humid climate is required. The effectiveness of each passive cooling method was measured by comparing the percentage of compliance of the calculated indoor operative temperature (T_{op}) to the predicted T_{op} under the relevant international adaptive comfort standards. The findings of this type of study will contribute to the improvement of terrace house design and invention of new approach to resolve thermal comfort in terrace house by using building retrofitting methods, instead of conventional passive cooling with natural ventilation approach.

1.2 Problem Statement

As reported by Malaysian Metrological Department annual report, in 2019, the average temperature in Malaysia was 27.63 °C, it was 0.69 °C higher than the normal temperature of 26.94 °C recorded in previous years. In addition to the rise of temperature, Malaysia was hit twice by heat wave in 2019 with a recorded maximum daily temperature between 37.1 °C to 38.0 °C. The recorded extremely high temperature has triggered the alert on the high temperature in the country. The alert level on daily maximum temperature set in Malaysia is 35 °C to 37 °C.

Further to that, the report by United Nations on world energy consumption, electricity contributed 19% of total world energy consumption, and 27% of it was used by households. Space cooling is the fastest growing use of energy in buildings. Another report by International Energy Agency on world energy consumption reported the share of cooling in total energy use in buildings rose from about 2.5% to 6% from 1990 to 2016. In case of a tropical country such as Malaysia, in year 2016, 11% of electricity consumed in residential sector is for space cooling purpose.

This fraction is expected to increase due to the increase of dependency of air-conditioners to achieve thermal comfort accompanied by the economic growth as well as future climate change. The high cost on installation of AC and high energy consumption of this active cooling system is not an environmentally friendly system and not an affordable system to low-income people. On the other hand, considering the persistent gap between rich and poor in developing countries, it is highly likely that

low-income people will remain to be exposed to the heat risk elevated by global climate change.

Under these circumstances, to resolve this problem, simple effective and low-cost cooling strategies for residential buildings located in tropical developing countries are strongly needed. Passive cooling strategy without using much energy was the common approach as solution to resolve the high cost and high energy consumption due to active cooling in buildings. Passive cooling strategies that commonly used are provision of cross natural ventilation through the building as cooling agent to remove trapped heat in the building, installation of cool roof to reduce transmission of heat from roof to the building, and provision of shading device on the wall and windows to avoid direct heat transmission from the sunlight to the building.

In recent years, smart-house technologies, which consist of various energy-efficient appliances, roof-top photovoltaic (PV) solar panels, and home energy management systems, have attracted social attention to achieve the energy saving, low carbon, and comfort indoor environment. However, such cutting-edge technologies are still not affordable for most developing countries due to the financial conditions. Although it is already widely known that solar heat gain through the roof is major in low-rise terrace house, and solar shielding of roof should contribute to the reduction of primary heat gain in low-rise buildings, but this common knowledge has not been implemented as affordable design for houses in many developing countries. It is the gap between knowledge in academic community and the construction industry and policy makers.

Therefore, in this research, the main objective is to develop a low-cost passive cooling method that easy to apply to residential buildings in tropical developing countries. The study was conducted through field measurement to collect real data on how the indoor thermal conditions was changed upon application of different natural ventilation strategies and simple building retrofitting methods to the building. The results were compared to the relevant international adaptive comfort standards by comparing the T_{op} in the building. The effectiveness of each passive cooling method was measured by comparing the percentage of compliance of the calculated indoor T_{op}

to the predicted T_{op} under the relevant international standards. ASHRAE defined T_{op} as the uniform temperature of an imaginary black enclosure and air within in which an occupant would exchange same amount of heat by radiation and convection as in the actual non-uniform environment. In building design, T_{op} can be defined as the average of the mean radiant and ambient air temperatures, weighted by their respective heat transfer coefficients. The best performance method with higher compliance with the standards was concluded at the end of this study to introduce a low-cost and easy passive cooling method for residential building in hot and humid climate countries.

1.3 Research Questions

Based on the problems identified in problem statement, the research questions of this study were established as follows:

- (a) How different natural ventilation strategies by opening window at daytime and night time affected the operative temperature in terrace house under hot and humid climate?
- (b) Will a natural ventilated terrace house required additional building retrofitting method to compliment the thermal conditions?
- (c) What is the level of compliance of these passive cooling strategies, when comparing with the relevant international standards on thermal comfort?

1.4 Research Objectives

After summarized the background of the problem and to answer the research questions, three objectives in this research are:

- (a) To evaluate the performance on thermal conditions (air temperature, relative humidity, air velocity) of passive cooling with different natural ventilation strategies for terrace house under hot and humid climate.

- (b) To assess the performance on thermal conditions (air temperature, relative humidity, air velocity) of passive cooling with different building retrofitting methods for terrace house under hot and humid climate.
- (c) To analyse the indoor thermal comfort level of the proposed passive cooling strategies based on international adaptive comfort standards.

1.5 Research Scope

Literature reviews on previous research on passive cooling and building retrofit for residential buildings was performed. Field measurement was conducted in a two-storey terrace house in Kuala Lumpur, Malaysia in tropical region with hot and humid climate. The measurement was conducted in two stages. In the first stage, four natural ventilation strategies: without ventilation, full ventilation, day ventilation and night ventilation were studied to evaluate the thermal performance of the house based on the operative temperature. First stage was conducted for four weeks from February to March 2018 to measure air temperature, globe temperature, relative humidity, air velocity in the house; besides surface temperature of ceiling, roof and external wall were measured. Simultaneously, outdoor air temperature, relative humidity and wind speed were measured. Operative temperature was calculated based on the measured data to check on the compliance to the international adaptive comfort standards. In later stage with building retrofitting methods, four cases with different combination of building retrofitting strategies were studied. The same parameters of measurement were carried out for 14 weeks from September to December 2018 and followed by the same study on compliance of operative temperature to international adaptive comfort standards.

1.6 Significance of Research

The findings of this study provide data towards future house design with passive cooling strategies by adopting different ventilation modes and building retrofitting. The findings can be applied to a terrace house design, and particularly to

window design, to control natural ventilation in residential buildings. Furthermore, a low cost and low technology passive cooling method using building retrofitting was proposed. This method of passive cooling will benefit landed low cost houses in hot-humid regions, especially from developing countries, such as Malaysia, Indonesia and Thailand. Besides that, at remote area without electricity to use fan or air-conditioner, roof cover is an effective passive cooling method to be applied.

1.7 Organization of Thesis

This thesis was compiled in seven chapters.

Chapter 1 introduces the thesis with an overview to the thesis, problem background, problem statement, research questions, research objectives, research scope, significance of research, and organization of the thesis.

In Chapter 2, a review on the literature related to this research topic, particularly on passive cooling on residential buildings, various types of air ventilation, and building retrofitting method. At the end of this chapter, research gap was identified.

Chapter 3 describes the research methods applied in this research. The location, details and climatic description of the investigated house were mentioned. Field measurement process including preparation of equipment, setup of equipment, stages of data collection, and method of data analysis were comprehensively explained.

Chapter 4 presents the results from stage 1 measurement on natural ventilation strategies and follows by discussion on findings from the analysis of the data. The indoor and outdoor thermal conditions of the investigated house under different natural ventilation strategies were analysed, compared and discussed. Furthermore, vertical profile of indoor air temperature under natural ventilation and mixed-mode ventilation were compared. Influence of surface temperature on indoor air temperature was analysed. Stage 1 was summarised based the first objective of this research.

Chapter 5 presents the results from stage 2 measurement on four cases with different combination of natural ventilation, building retrofitting methods, and active cooling method. The indoor and outdoor thermal conditions of the investigated master bedroom under different cases were analysed, compared, and discussed. Relationship between indoor and outdoor air temperature, comparison between indoor and outdoor thermal conditions, comparison on vertical temperature profile under different building retrofitting methods, and effect of roof cover on indoor thermal environments were analysed and discussed. Based on the summary, this chapter summarised the achievement of second objective of this research.

Chapter 6 presented the analysis and discussion of this research on different natural ventilation strategies and building retrofitting methods in comparison to relevant international standards using adaptive comfort standards. The percentage of compliance from each strategy and method was discussed. The achievement on the third objective of this research was discussed at the end of this chapter.

Chapter 7 summarise the research outcomes and conclusions drawn. The significance contribution and application of the findings are discussed. Finally, future works from this research were proposed.

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LIST OF PUBLICATIONS

Journal with Impact Factor

1. **N. Wai Tuck**, S.A. Zaki, A. Hagishima, H.B. Rijal, M.A. Zakaria, F. Yakub. (2018). Effectiveness of free running passive cooling strategies for indoor thermal environments: Example from a two-storey corner terrace house in Malaysia. *Building and Environment*, 160. <https://doi.org/10.1016/j.buildenv.2019.106214>. (Q1, IF: 5.379)
2. **N. Wai Tuck**, S.A. Zaki, A. Hagishima, H.B. Rijal, F. Yakub. (2019). Roof cover as an effective building retrofit for thermal comfort in residential buildings in Malaysia with a hot–humid climate. *Building and Energy*. (manuscript submitted on 29 November 2019)

Patent Filing

Title: Shaded Roof

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Conference Proceedings

1. **N. Wai Tuck**, S.A. Zaki, A. Hagishima, F. Yakub, M.A. Zakaria. (2018). Field measurement of indoor thermal environments in a two-storey corner terrace house in hot-humid climate. In *The 4th International Conference on Low Carbon Asia (ICLCA 2018)* (73-78).
2. **N. Wai Tuck**, S.A. Zaki, A. Hagishima, H.B. Rijal, M.A. Zakaria, F. Yakub. (2018). Investigation of indoor thermal environments in a typical two-storey corner terrace house in Malaysia. In *The 5th International Seminar on Tropical Eco-Settlements*.