Mixed Research Tools for Thermal Comfort Studies of Medium Density Mass Housing

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ABSTRACT

This paper describes the methodology used in the investigation of thermal comfort studies with the notion that energy efficient design adapted to double-storey terraced houses in Malaysia can increase thermal comfort and decrease energy consumption. The study requires a method of exploring the thermal performance of existing and hypothetical dwellings. Hence, the paper aims to determine that, if from the outset, houses are designed by taking into consideration energy efficient design strategies; in this case, orientation studies and the utilisation of passive design features, the result will be dwellings with lower internal temperatures and thus, lower energy consumption. Utilising three different methods of investigations: the questionnaire survey, temperature survey and computer simulation to corroborate findings from each, this paper describes the process undertaken. The triangulation of the mixed methods validated the findings to the problems identified in this study indicating increment of thermal comfort and reduction of energy consumption.

Keywords: thermal comfort, terraced-houses, questionnaire survey, data monitoring, computer simulation.

INTRODUCTION

Malaysia has experienced rapid economic development and social transformation in the past four decades, characterised by rapid urbanisation due to substantial population growth, which has in turn resulted in intensification in the demand for housing (Mohd Razali 2002). Due to this phenomenon, many houses were urgently built, frequently being planned and designed without much forethought about the attributes of the local climate. As a consequence, these newly built houses are uncomfortable and hot (Davis, Shanmugavelu, & Adam 1997) and this has resulted in an increased use of energy for cooling (Byrd 2006).

Housing stock in Malaysia has increased and the latest residential property stock report for the second quarter (Q2) in 2013 puts the housing stock in Malaysia of all residential types at 4,264,649 units (National Property Information Center 2013). Terraced house types, consisting of single, double and even triple-storey houses, from all price brackets, constitute the largest type division, 40% or 1,712,808 units of the national housing stock and represent the most popular housing type (Phoon 2004). With the rise of the housing stock the use of electrical energy in the residential sector inevitably increases as well. According to the national energy data available, energy consumption in the residential sector has increased from 17.5% in 2002 to 21% in 2006 (Energy Commission Malaysia 2005). This increment is interlinked with the

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rise in the progressive efforts of the nation to develop which resulted in the emergence of the middle-class population in Malaysia (Torii 2003) which is, in turn, partly responsible for steering the trend toward an energy–intense lifestyle.

AIM OF THE STUDY AND QUESTIONS

The aim of the study is to investigate the potential passive design strategies in typical medium density terraced houses in Malaysia in order to be energy efficient and yet achieve thermal comfort for the occupants as well. The paper seeks to answer three key research questions: whether the existing terraced houses provide satisfactory and adequate thermal comfort; do orientations of the houses have any impact on thermal comfort conditions and energy consumption and can any passive design strategies improve the conditions and reduce energy use? The information gathered will become the basis for all involved in the designing of the residential sector (especially for terraced houses) in Malaysia to rethink of a new design paradigm for the conventional approach of house building with particular attention to medium density construction.

THE PROBLEM

Malaysia is situated in the hot and humid equatorial region, where daily temperatures are always hot between 24˚ - 34˚C. It is slightly cooler when it rains. Coupled with high humidity (averaging more than 80% most of the year) and compounded by a lack of wind flow, thermal comfort is difficult to attain naturally. As a consequence, artificial ventilation is required almost all the time because internal conditions become hot and uncomfortable, not only during the day, but also well into the night. Studies have found that night-time internal temperatures in terraced houses usually remain on the upper limit of the thermal comfort zone until the early hours of the morning (Davis, Shanmugavelu, & Adam 1997, Noor Aziah 2008). This necessitates some form of artificial cooling and of late the use of air conditioning has become ubiquitous. Due to this the use of electrical energy in the residential sector has increased tremendously in recent years. On top of that, ownership of air conditioner units in 2005 had increased by 32% since 1999 and this is predicted to increase to almost 60% by the year 2015 if the present trend persists (Saidur, Masjuki, Jamaluddin & Ahmed 2007). As a consequence, energy demand will also be on the rise.

As mentioned previously, terraced houses is the most popular house type in Malaysia and have been built since the 1970s. Although they have been built for almost 50 years, the house designs remained much the same due to the limited block. The houses have only two facades: with openings for ventilation only in the front and the back. This meant the orientations of the houses are crucial for the thermal comfort of the occupants. Houses that are orientated facing east and west faced the worst thermal conditions.

RESEARCH METHODS

The research methods applied in this study aim, first of all, to investigate the research questions outlined above and then to corroborate and validate them with different methods in order to consolidate the study. To assist in understanding the whole scenario of thermal problems and their contribution to thermal comfort and energy consumption as previously described, an ‘applied’ research approach was selected. In other words, the chosen method addresses real life situations that require immediate attention, being *"...primarily interested in identifying problem areas, searching for relevant solutions and producing direct answers"* (Sarantakos 2005, pp: 322). The methodology involved three research instruments:

- The first tool provides a method of investigating and analysing existing conditions in double storey terraced houses through a field survey using a questionnaire and interview technique.
- The second tool also analysed existing conditions but through a temperature monitoring procedure where data loggers were used to collect temperature data.
- The third tool is computer simulation studies which seek to predict the most suitable and appropriate energy efficient design strategy for double storey terraced houses.

RESEARCH PROCESS

In seeking answers posed by the research questions, three distinct approaches were adopted, as illustrated in Figure 1 and explained below:

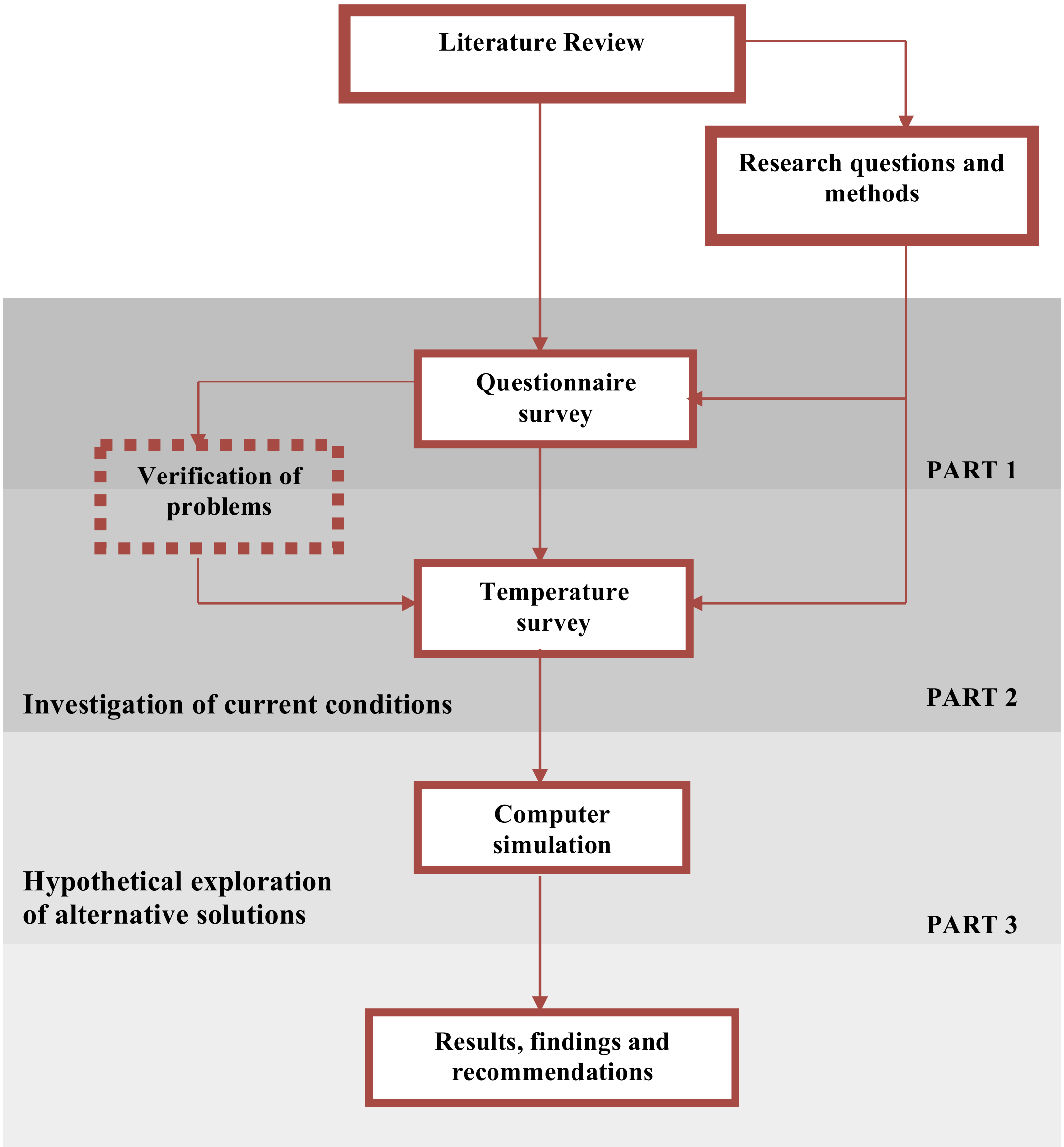

Figure 1: The research process

Part 1 seeks the residents' opinions with regard to their thermal comfort and the factors affecting it within their houses. This is established through a questionnaire survey of their opinions. These opinions will underpin the crux of the research statement and claim that most terraced houses in Malaysia are indeed overheated and uncomfortable to live in during most parts of the day. The occupants' perceptions of what is suitable or unsuitable about their dwellings are also important, as this will form the basis for the implementation of design solutions within the context of passive design for thermal comfort and energy use.

In **Part 2** the current conditions of the terraced houses are surveyed by monitoring the internal temperatures of the houses. This investigation will reveal the indoor thermal conditions of the houses and whether houses facing different orientations display different thermal conditions and performances. The findings from this part will be used to corroborate results found in the first and third investigations. For Parts 1 and 2, a cross-sectional survey was considered the most feasible means of research. The reasons for the use of the survey are, firstly, that it studies only a small sample of the population in its existing settings at a given moment, investigating a particular set of conditions with no manipulations being involved, to reduce bias in the study (Babbie 1990); and secondly, an empirical generalisation and representation from studying a small sample can be maximised in relation to a bigger population (Hammersley 1993). Finally, and most importantly this method is prudent in regard to time and money, compared to the daunting task of conducting a large-scale study involving all terraced houses in Malaysia.

Part 3 is a parametric exploration of the energy and thermal performances of hypothetical dwelling models, tested through computer simulation. The exploration will be based on findings from data collected from the first two investigations above. The computer simulation will also facilitate passive design strategies for the houses, focusing on variation of orientation and envelope design as the main considerations. Findings from this investigation will consolidate all results and form the basis for design guidelines for future energy-efficient design of terraced houses.

LOCATION OF STUDY

The study is concerned with medium density terraced houses in Malaysia. The housing estate concerned in this study is located at Kota Damansara in Selangor, which is a mini township of mixed development, comprising of all types of residential buildings from the various price brackets, commercial and industrial areas. It is about 25 km from Kuala Lumpur and due to this close proximity; it enjoys a suburban style of living with increasing property values. The double-storey terraced houses in this study are either made up of intermediate, end or corner lots, but all are of similar design. The only difference is that the corner or end lots have windows and openings on the side walls, as shown in Figure 2.

Figure 2: Terraced houses used in the study.
(Source: Author, 2008)

The next section will describe in brief the processes of the questionnaire survey; temperature survey and in more detail on the computer simulation.

PART 1 - QUESTIONNAIRE SURVEY

For extracting information regarding occupants of the houses a cross-sectional survey was conducted, which, "…*solicits response at one point in time from a sample selected to describe some larger population at that particular time*" (Babbie 1990, pp: 72). This procedure is a method of gathering information from a sample of individuals, drawn from just a fraction of the total population being studied. One of its advantages is that it, "…*enables a researcher to cover extensive amount of information – from demographic characteristics to behavioural habits, to opinions or attitudes on a variety of topics – across a large number of people in a limited amount of time*" (Wang & Groat 2002, pp: 278).

This survey method is particularly suitable for the first part of the study, which aimed to ascertain whether or not the occupants were currently thermally comfortable in their variously oriented houses, and what efforts were made to achieve and maintain thermal comfort. The questions were designed to ascertain if there were any relationships between the orientations of the houses with their occupants' perceptions of thermal comfort. Occupants were also asked about their adaptive activities in response to discomfort, such as opening or closing windows. These would later form the basis for determining occupants' acceptance of higher comfort temperatures, as suggested by adaptive thermal comfort standards. Questions on thermal comfort were based on tested studies and referred literatures (Parsons 2003; Kishnani 2002; de Dear, Brager & Cooper 1997; ASHRAE 1992; Fanger 1972).

The opinions were presented using a semantic scale rating assessment based on ASHRAE comfort scale. The questionnaire was designed to be either self-administered or through interview. Interactive semi-structured interviews were undertaken in the respondents' own dwellings. The interviews were designed to take between 30 and 40 minutes for each household. The objective of these questions was to establish whether or not the houses are actually hot and uncomfortable by analysing the responses. This information was corroborated with logged temperature data, which was done simultaneously during the field work. It should be noted that respondents were asked to answer these questions under normal conditions, with fans switched on but no air conditioning.

After an intensive and an exhausting fieldwork, which took a period of almost three months, a total of 85 households had been interviewed and temperatures from 22 houses had been logged. Although purposive sampling was employed, the criteria still adhered to the parameters of the study; which required houses with different orientations and locations. The total number of cases corresponded to 35% of N (total population of 240) and 58% of S (sample size of a given population, according to the table for determining sample size of a given population, pp: 173 in Sarantakos (2005)). According to Sarantakos (2005) this is considered as probable for the number to be meaningful for analysis purposes. Table 1 shows the final numbers of respondents with respect to the orientation groups.

Table 1: Number of houses interviewed in relation to orientation groups.

Orientation Group	No. of respondents
1. North West – North East (NW-NE) (316-360˚ & 0-45˚)	23
2. North East – South East (NE-SE) (46 – 135˚)	18
3. South East – South West (SE-SW) (136-225˚)	25
4. South West – North West (SW-NW) (226-315˚)	19
Total	**85**

Analysing data

The data gathered from the questionnaire survey were analysed using statistical methods. Most of the data were nominal and ordinal therefore descriptive statistics such as frequency; cross tabulation and analysis of variances (ANOVA) were used as the methods of assessment. Data reduction was also done when required to assist the researcher in grouping some of the feedback to make more sense of their relationships. The statistical software SPSS 12.0 was used initially and was later upgraded to versions 13.0, 14.0 and 15.0. The main aim of the analyses was to establish the relationship between orientation, energy consumption and usage patterns towards achieving thermal comfort.

PART 2 - TEMPERATURE SURVEY

Having addressed how the occupants perceived their houses' performances, we then considered how the houses actually performed in terms of indoor conditions to corroborate findings from Part I. A temperature survey was conducted, intended to establish if a significant difference is evident in the indoor temperatures and energy consumption of houses of differing orientations. Data monitoring was undertaken as a complimentary method to help substantiate findings from the results of the questionnaire survey above.

Selected houses were monitored for a period of at least five to seven days. This was assumed to be adequate for obtaining consistent indoor conditions since the climate of Malaysia has little daily variation. The data loggers used were the Gemini 'Tinytalk II' automatic data loggers with external sensing probes. The loggers were programmed to measure dry-bulb air temperature at one-hour intervals. The dry bulb temperature in two different rooms was monitored along with the outdoor conditions. The data loggers were placed in the living room in the lower level, the master bedroom on the upper level and under the porch area in the front of the house. Each data logger in the rooms was placed at the body height of a seated person between 0.9

to 1.5 meters as referred to in the standard. In each case the loggers were positioned away from direct sunlight and from any obvious direct heat and cold sources and windows or other external openings. External climatic data including temperatures, relative humidity, wind speed and direction, rainfall and solar irradiation data were collated from the Malaysia Meteorological Services from Subang station during the logging duration.

Analysing data

All logged data were offloaded from data loggers into the 'TinyTalk' program before being further exported into spreadsheets for analysis, using the Excel and SPSS programs. Graphs and charts in Excel indicate trends, enabling the making of comparisons between the data. The analysis of variance (ANOVA) and the t-test using the SPSS program were conducted on the temperature data to see whether any differences of temperature occurred among houses of varying orientations.

PART 3 - COMPUTER SIMULATION

Parametric analysis has been widely used to investigate the influence of building characteristics on thermal and energy performances of buildings (Norhati 2006; Jahnkassim 2004; Hong, Chou & Bong 2000). This part of the study took a predictive approach, whereby the performance of a base-case model and potential improved models with varying passive design features were tested and quantified using computer simulation techniques on a number of orientations. This tool enabled exploration of the most suitable and appropriate passive design strategy for more energy-efficient double storey terraced houses. The passive design measures examining factors affecting thermal requirements and energy consumption were the orientation and envelope parameters.

Tool for parametric analysis - IES <VE>

To be suitable for use in this study, a tool must be one that is used in the building energy field and utilises whole-building energy simulation programs that provide key building performance indicators, such as energy use and demand, temperature, humidity and costs (Crawley et al. 2005). The tool should also allow users to predict the thermal performance of buildings and also to predict the cost effectiveness of energy use and consumption. Another important criterion in the selection of the most appropriate tool is the availability of technical and software support (Mason 1999). The Integrated Environmental Solution (IES <VE>) thermal simulation package, consisting of a range of design-oriented building analyses within a single software environment, conformed to all these selection criteria and was chosen as the most appropriate tool for the study.

IES <VE> incorporates the thermal simulation program ApacheSim with various other sub-programs of particular interest for this study. The idea is that the single model allows easy data exchange among applications. The philosophy behind the IES <VE> program is to provide an integrated suite of programs linked by a common data model generator, the Integrated Data Model (IDM). The accuracy of thermal analysis within the APACHE system has been validated by various studies including the Low-Energy Office Building for the Ministry of Energy, Communication and Multimedia in the Administration Capital at Putrajaya (DANIDA & MECM 2002; Lomas et al. 1997) and can be generally accepted as providing realistic conditions.

To be able to understand the performances of the houses according to orientation, a computer simulation study aimed to predict energy and thermal performance for directions covering the full 360° at 10° intervals was done. The simulations were done to discover whether houses facing different directions have different energy loads and consequently, different thermal performance, as shown in Figure 3.

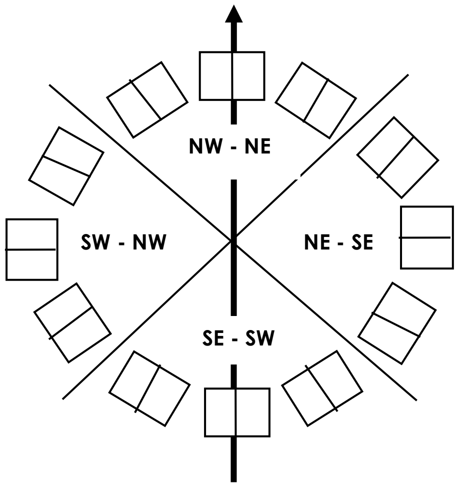

Figure 3: The orientation parameters of terraced houses studied.

The following simulation steps were then undertaken, as shown in Figure 4.

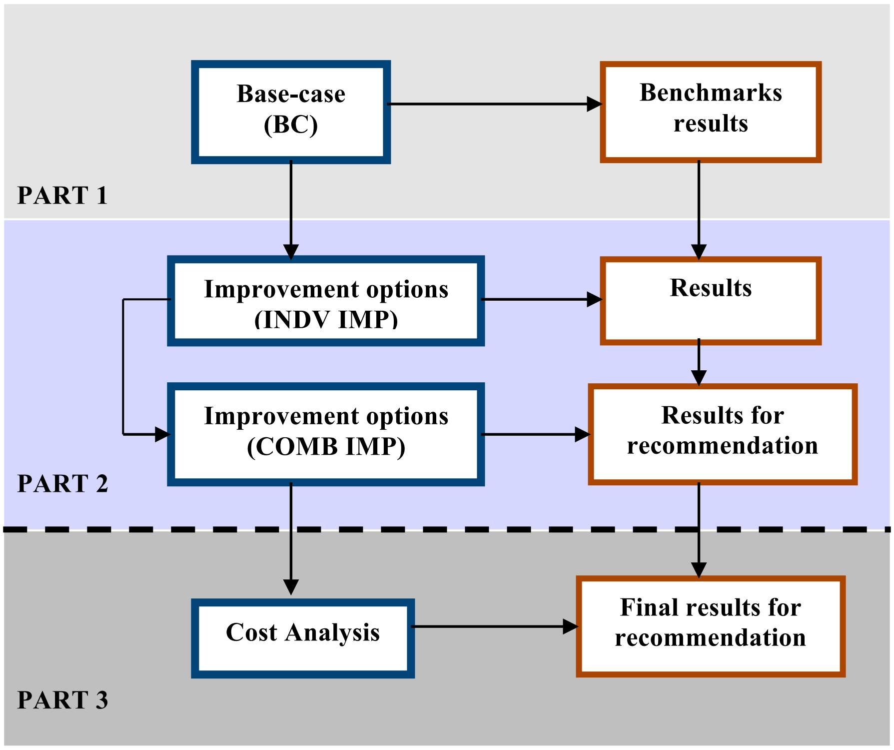

Figure 4: Components of simulation study and cost analysis

Part 1 simulates the Base-Case (BC) conditions; Part 2 simulates the Improvement (IMP) conditions, while Part 3 (not a computer simulation) is the cost analysis based on the simulation results.

Simulation Part 1: Base-case (BC) model

In this study the areas of concern that will affect the energy consumption and heat gain are the envelope components: roof, external walls and glazing on windows or doors. Therefore, these three components were employed with various interchangeable materials. Table 2 indicates the construction properties and U-values of the BC model.

Table 2: Base-case model profile for external wall, roof and glazing for simulation studies

Building Component		Thickness (mm)	U-value (W/m²K)
Wall1 [W1]	½ - brick thick with plaster on both sides	150	1.7731
Roof1 [R1]	Concrete roof tile with aluminium foil on timber truss and plasterboard ceiling		1.7201
Glazing1 [G1]	Single clear float	6	5.600

Simulation Part 2: Parametric analysis of Improvement (IMP) model

In Part 2, parametric analyses were performed to assess, primarily, the annual energy consumption (AEC) and thermal performance of the IMP models, considering various envelope configurations as tabulated in Table 3.

Table 3: Modified improvements to BC conditions undertaken for the simulation studies

Improved Roof		Thickness (mm)	u-value (W/m²K)
Roof2 [R2]	Concrete roof tile on timber truss with 25 mm glasswool insulation		0.8620
Roof3 [R3]	Concrete roof tile on timber truss with 50 mm glasswool insulation		0.5624
Roof4 [R4]	Concrete roof tile on timber truss with 75 mm glasswool insulation		0.4071
Roof5 [R5]	Concrete roof tile on timber truss with 100 mm glasswool insulation		0.3245
Improved Wall			
Wall2 [W2]	½-brick thick wall with 25 mm glasswool insulation and plasterboard	170	0.5854
Wall3 [W3]	½ brick thick wall with 50 mm glasswool insulation and plasterboard	195	0.4286
Wall4 [W4]	½ brick thick wall with 75 mm glasswool insulation and plasterboard	220	0.3380
Improved Glazing			
Glaze2 [G2]	Double-tinted glazing	10	2.805

The next sections describe the various improvements to the building envelope components undertaken for the simulation study.

Roof: Improvements using insulation

The improved roof component, utilising varying thicknesses of glasswool insulation (25mm, 50mm, 75mm and 100mm). The existing roof construction consists of (in order of external to internal): 10mm thick concrete roof tiles; on 25mm timber battens; aluminium foil; 150mm timber rafter and 10mm gypsum plasterboard. The improved roof [R2-R5] included varying thicknesses of glasswool insulation between the rafter and the plasterboard ceiling.

Walls: Improvements using insulation

For improvement studies of the wall, three varying wall constructions were investigated. The BC is represented by a 150mm plastered ½-brick wall [W1] with a u-value of 1.7731 W/m^2K. Walls with insulation are uncommon, but were investigated. Figure 6 shows the different types of the improved wall constructions used in the investigation.

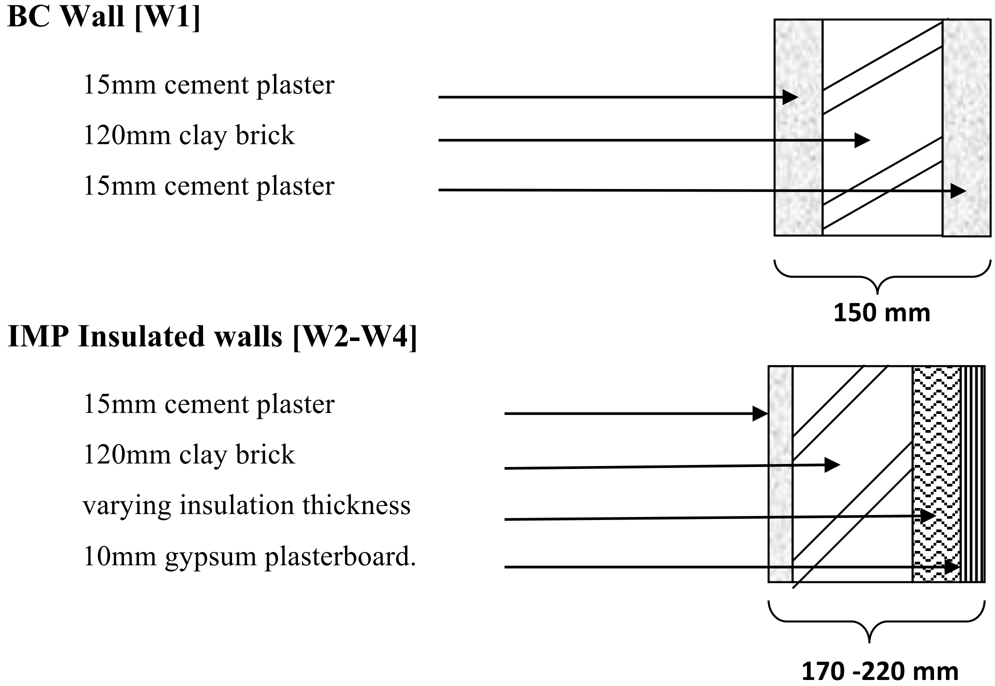

Figure 5: BC wall and insulated wall constructions

Glazing: Improvement using lower-transmittance glass

Glazing used in the BC model is 6mm thick clear float glass. For the improved model [G2] tinted double-glazing 10 mm thick was used.

The simulations for the IMP models were done in two steps:

i) Step 1: AEC of Individual Improvement (INDV IMP) models

Step 1 simulated the improvements to the building envelope individually. For the Individual Improvement (INDV IMP) tests each building component was tested on its own, with the other two components remaining constant in line with the BC. For example improvements [R2] to [R5] were tested with [W1] and [G1] remained constant and consequently improvements [W2] to [W4] were tested with [R1] and [G1]. Lastly improvement [G2] was tested with [R1] and [W1]. A total of eight (4

Roof; 3 Wall and 1 Glazing) INDV IMPs were simulated for 36 orientations giving a total of 396 permutations (excluding the BC). The steps are shown in Table 4.

Table 4: Series of INDV IMP permutations for Roof, Wall and Glazing options

Roof	Wall	Glazing
R1W1G1(BC)	W1R1G1 (BC)	G1R1W1 (BC)
R2W1G1	W2R1G1	G2R1W1
R3W1G1	W3R1G1	
R4W1G1	W4R1G1	
R5W1G1		

Based on the findings from Step 1, Step 2 takes the parametric studies further by simulating the remaining combined effect of the improvements. The results of these simulations will provide further analyses for cost analysis, as will be explained next.

ii) Step 2: AEC of Combined Improvement (COMB IMP) models

As mentioned previously, in Step 1 for INDV IMP (individual improvements) the following options were retained for further testing in Step 2: 3 Roof options: [R1], [R2] and [R3]; 2 Wall options: [W1] and [W2]; and 2 Glazing options [G1] and [G2]. The options were then combined and the variations of Combined Improvements (COMB IMP) are shown in Table 6. The COMB IMP gives a total of 12 variations (of which the four indicated by * were already undertaken in Step 1), resulting in a final total of 288 simulation permutations.

Table 6: Series of combinations of COMB IMP options

Roof1			Roof2			Roof3		
*R1	W1	G1	R2	W1	G1	R3	W1	G1
R1	W1	G2	R2	W1	G2	R3	W1	G2
R1	W2	G1	R2	W2	G1	R3	W2	G1
R1	W2	G2	R2	W2	G2	R3	W2	G2

The AEC data gathered from this simulation will provide a notion of how substantial AEC penalties might be should orientations of buildings stray from the optimum. Several examples of data will be worked out and using curvilinear regression, a mathematical formulation of the penalties provided, explained next.

RESULTS AND FINDINGS

a) Energy performance

Simulations of the AEC for the different COMB IMP revealed the option using [R3W2G2] or 50 mm insulation in the roof; 25 mm insulation in the walls and double glazing presented the best AEC savings difference with the BC option. [R3W2G2] predicted an average AEC of 6155 kWh/yr, 1634 kWh/yr less than the BC scenario. The optimum orientation is between 270º – 320º (W - NW). Although East orientations still show the highest consumption, after subjecting the figures to statistical analysis, the results show no significant differences among the AECs of all orientations. Therefore, utilizing [R3W2G2], suggested that the orientation parameters have no influence on the house's annual energy consumption. From the results, due to the improved strategies of utilising insulation in the roof and walls and double glazing for windows the energy consumption differences between the terraced houses from all orientations is slight. The inference is that when terraced houses are protected energy usage can be optimized: even for houses facing both east and west which usually have a higher energy use.

b) Temperature performance

Similar to findings from the energy performance, simulations of the thermal performance also indicated that lowest temperatures are predicted for the option utilizing [R3W2G2]. Figure 6 summarizes the differences in temperatures among the design options when applied to each of the four orientations.

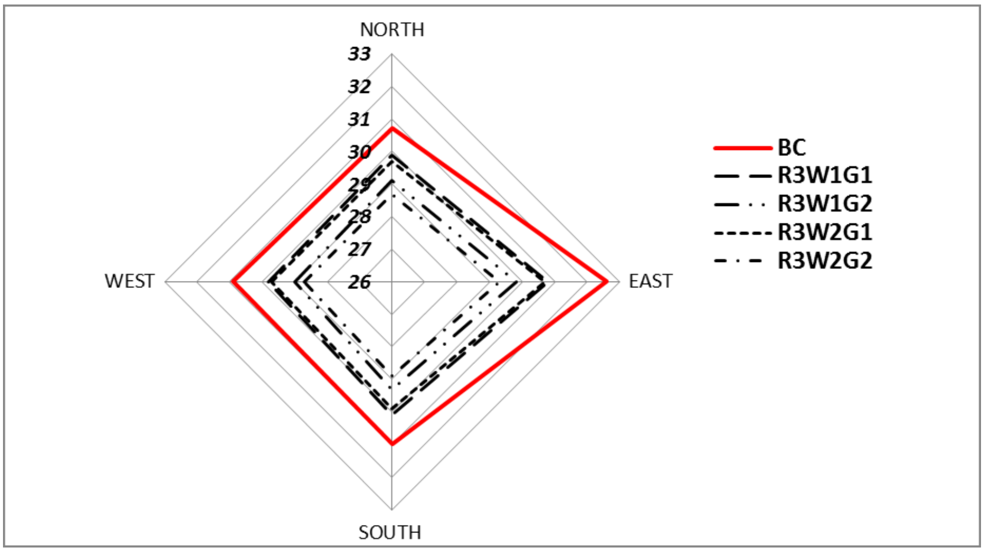

Figure 6: Differences in mean temperatures of the COMB IMP ROOF3 models at four different orientations with the BC

The figure indicated that the highest temperatures occurred in the east orientation as in previous analyses, with option [R3W2G2] showing the lowest temperatures among the four options. The graph also shows a distinct difference in thermal performance between utilizing walls with insulation [W2] and without insulation [W1] with the former showing better results. The figure also shows the BC temperature performance profile (in red) where the highest temperature difference between BC and the best COMB IMP [R3W2G2] is 2 to 3 K, indicating better thermal performance for the improved options.

c) Regression analysis

Based on the simulations, the AEC data and optimum orientations were determined for the different IMP options. The next step was to provide a means for designers to use this data with simple mathematical calculation procedures to gauge the energy implications of orientation on their buildings.

A curvilinear regression analysis was performed to find the relationship between the AEC penalties as the dependent variable (y-axis) and the range of orientations from the optimum orientation as the independent variable (x-axis) for all the IMP options. From the analysis the best curve-fit regression line is denoted by Equation 1. For this discussion, only the best results from the COMB IMP options will be used as examples, such as: [R1W2G2]; [R2W2G2] and [R3W2G2] (details are shown in Appendix 1.

Equation 1: $Y = a + b_1 x_1 + b_2 x_1^2$

Where,

Y= predicted or dependent variable
a = constant (slope)
x = independent variable (explanatory variable)
b = intercept of x-axis on y-axis

From the regression analysis, the mathematical equations for the three COMB IMP options selected are as follows:

For [R1W2G2];
Equation 2: $y = 19.948 + .767(x) + .22(x^2)$

For [R2W2G2];
Equation 3: $y = 22.471 + 1.063(x) + .233(x^2)$

For [R3W2G2];
Equation 4: $y = 4.25 + .213(x) + .07(x^2)$

Where, (x) denotes each percentage of ranges (5%, 10%, 15% or 20%), either clockwise or anticlockwise from the optimum orientation.

The equations are used to calculate the AEC penalties for the different COMB IMP options. The equations can help designers to predict energy consumption for the houses should they stray from the optimum orientation.

COST ANALYSIS

The cost analysis in Part 3 is not part of the IES<VE> simulation: however, results from ApacheSim can be downloaded into an Excel spreadsheet program for final analysis. Here the energy consumption data in kWh was converted into Ringgit Malaysia (RM) to look at the cost viability of the strategies. The aim is to investigate the relationship between having a more energy efficient house and the capital expenditure of the required improvements. It is common knowledge that any improvements or modifications to a building will increase the required capital expenditure. Whether or not the investment is prudent will be determined by discovering the period of time required to recover expenditure and comparing it to the cost of energy consumption in the improved models.

SUMMARY

The chapter has summarised all of the three research methods undertaken in the study: the **questionnaire survey**; the **temperature survey**; and the **computer simulation,** together with the analyses methods. The first two methods are in the nature of an enquiry, seeking to investigate and establish the first two Key Research questions about thermal comfort: whether the houses have acceptable thermal conditions, whether occupants feel comfortable and whether the orientation of the houses has any impact on thermal conditions and energy consumption. The third method, undertaking computer simulation, is exploratory and predictive in nature. This method aims to consolidate data found by the first two methods by simulating models that are close to real situations. In answering Key Research question 3 this method will also predict the energy and thermal performance of hypothetical models for all orientations utilising passive design features and strategies.

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