PREDICTION OF INDOOR ENVIRONMENTAL PARAMETERS FOR NATURALLY VENTILATED BUILDING USING ARTIFICIAL NEURAL NETWORK: A REFLECTION OF OUTDOOR PARAMETERS

SURAYA BINTI GHAZALI

A thesis submitted in fulfillment of the requirement for the award of the Degree of Master of Civil and Environmental Engineering

Faculty of Civil and Environmental Engineering
Universiti Tun Hussein Onn Malaysia

APRIL 2015
ABSTRACT

This research investigates the environment condition within two types of buildings, naturally ventilated and air-conditioned to gain better understanding of the indoor environment condition of the selected buildings. The main purpose of this study is to develop predictive model to forecast indoor environmental parameters using Artificial Neural Network (ANN) technique. Field measurements were conducted at four traditional Malay houses in Peninsular Malaysia to acquire the actual indoor and outdoor data; and to provide data for network training during model development. Hourly time-series data of three indicators including: air temperature, relative humidity and air velocity were used to forecast the indoor environmental parameters. The performance of the developed model was evaluated using R squared ($R^2$) and Mean Square Error (MSE). Network testing was performed to validate the models developed. The accuracy of the model was measured using the Mean Absolute Percentage Error (MAPE). Results from the research show that twelve ANN models with the best structure were successfully developed to forecast indoor temperature, humidity and velocity. The MAPE values for the comparison between the actual and predicted for naturally ventilated building is less than 20 percent for indoor temperature and humidity which can be considered acceptable as suggested by many researchers. However, the MAPE value is more than 20 percent for indoor velocity. As for air-conditioned building, the MAPE values exceed 20 percent for all parameters. It was found that the developed models only applicable for naturally ventilated building. The models in general could predict indoor temperature and humidity pattern with modest accuracy. However, it is not applicable for air-conditioned building due to the different building characteristics.

Keywords: indoor environment, natural ventilation, prediction, Artificial Neural Network.
ABSTRAK


Kata Kunci: persekitaran dalaman, pengudaraan semula jadi, ramalan, Rangkaian Neural Buatan.
TABLE OF CONTENTS

TITLE ........................................................................................................................................... i
DECLARATION............................................................................................................................. ii
DEDICATION............................................................................................................................... iii
ACKNOWLEDGEMENT .............................................................................................................. iv
ABSTRACT ..................................................................................................................................... v
ABSTRAK ...................................................................................................................................... vi
TABLE OF CONTENTS ................................................................................................................ vii
LIST OF TABLES ....................................................................................................................... xi
LIST OF FIGURES ..................................................................................................................... xiv
LIST OF SYMBOLS AND ABBREVIATIONS .......................................................................... xvii
LIST OF APPENDIX ................................................................................................................... xviii

CHAPTER 1 ..................................................................................................................................... 1
INTRODUCTION ............................................................................................................................ 1
  1.1 Background of the Research ............................................................................................... 1
  1.2 Problem Statement ............................................................................................................ 5
  1.3 Aims and Objectives of the Research .............................................................................. 6
  1.4 Scopes and Limitations of the Research ......................................................................... 6
  1.5 Significance of the Research ............................................................................................ 7
  1.6 Organization of the Thesis ............................................................................................... 8
  1.7 Chapter Summary ............................................................................................................ 11

CHAPTER 2 ................................................................................................................................... 12
VERNACULAR ARCHITECTURE AND INDOOR ENVIRONMENT ............................................. 12
  2.1 Introduction ....................................................................................................................... 12
  2.2 General Characteristics of the Hot Humid Climate of Malaysia ..................................... 13
  2.3 Vernacular Architecture ................................................................................................... 16
        2.3.1 Malay Traditional Architecture ............................................................................... 17
        2.3.2 Characteristics of Malay Traditional Architecture ............................................... 18
2.4 Indoor Environmental Quality (IEQ) ................................................................. 23
  2.4.1 Thermal Comfort ....................................................................................... 25
  2.4.2 Factors Affecting Comfort ....................................................................... 26
  2.4.3 Criteria for Thermal Comfort in Malaysia .............................................. 28
2.5 Standards and Guidelines for Indoor Environmental Condition .............. 30
  2.5.1 ASHRAE Standard 55 – 1992 ................................................................. 30
  2.5.2 ISO Standard 7730 – 1994 ................................................................. 31
  2.5.3 CIBSE Guide – 1986 ........................................................................... 31
  2.5.4 MALAYSIAN Standard 1525 – 2007 ..................................................... 32
2.6 Review of Past Works .................................................................................... 33
  2.6.1 Indoor Environmental Condition Studies in Natural Ventilated Buildings ........................................................................................................ 33

2.7 Chapter Summary .......................................................................................... 34

CHAPTER 3 ........................................................................................................... 35
ARTIFICIAL NEURAL NETWORKS: THEORY AND APPLICATIONS..... 35

3.1 Introduction ..................................................................................................... 35
3.2 Brief Historical Review of Artificial Neural Networks (ANN) ............... 36
3.3 An Overview of ANNs .................................................................................. 37
3.4 ANN Applications in Indoor Environment Prediction ............................. 38
  3.4.1 Prediction of Prevalence of Building-Related Symptoms in Office Buildings ........................................................................................................ 38
  3.4.2 Indoor Air Quality Prediction ................................................................. 39
3.5 Definition of Artificial Neural Networks ...................................................... 40
3.6 Basic Concepts of ANNs .............................................................................. 41
  3.6.1 Biological and Artificial Neurons ........................................................... 41
  3.6.2 Neural Network Architectures ............................................................... 43
  3.6.3 Transfer Function .................................................................................... 45
  3.6.4 Learning Rules ....................................................................................... 46
3.7 Developing Multilayer Feed-forward Network for Forecasting ............... 47
  3.7.1 Architecture of Multilayer Feed-forward Network ............................... 47
  3.7.2 Transfer Function .................................................................................... 50
  3.7.3 Training Algorithm ................................................................................ 51
  3.7.4 Data Normalization .............................................................................. 53
# Table of Contents

## CHAPTER 3

3.7.5 Training Sample and Test Sample ........................................ 53
3.7.6 Performance Measures ................................................ 53
3.8 Justification for the choice of ANN to predict indoor environmental parameters ....................................................... 54
3.9 Limitation of ANN .......................................................... 54
3.10 Chapter Summary ......................................................... 56

## CHAPTER 4

RESEARCH METHODOLOGY .................................................. 58

4.1 Introduction ...................................................................... 58
4.2 Data Collection ................................................................... 60
  4.2.1 Environmental Parameters Measurement in Natural Ventilated Buildings ....................................................... 61
  4.2.2 Environmental Parameters Measurement in Air-Conditioned Building ......................................................... 65
4.3 ANN Model Development .................................................. 66
  4.3.1 Network Architecture Determination ............................... 68
  4.3.2 Training the Networks .................................................. 69
  4.3.3 Testing the Networks .................................................. 70
4.4 Chapter Summary .......................................................... 71

## CHAPTER 5

RESULTS AND DISCUSSIONS .................................................. 72

5.1 Introduction ...................................................................... 72
5.2 Location of Case Study .................................................... 73
5.3 Description of the Case Study Building with Natural Ventilation ........... 75
  5.3.1 Case Study in Johor (Southern region) ......................... 75
  5.3.2 Case Study in Negeri Sembilan (Central region) .............. 76
  5.3.3 Case Study in Kedah (Northern region) ......................... 77
5.4 Description of the Case Study Building with Air-conditioned ............... 78
5.5 Results, Data Analysis and Findings .................................... 80
  5.5.1 Environmental Parameters Measurement in Natural Ventilated buildings .................................................... 80
5.5.2 Environmental Parameters Measurement in air-conditioned building (at Library, UTHM)......................................................... 88
5.5.3 Results Comparison to Standard and Guideline ..................... 97
5.5.4 Indoor Conditions of the Case Study Buildings in Relation to Outdoor Conditions ................................................................. 98
5.6 Developing an ANN model for indoor environmental parameters forecasting .............................................................................. 103
  5.6.1 ANN model for Indoor Temperature Forecasting .................. 106
  5.6.2 ANN model for Indoor Humidity Forecasting ....................... 116
  5.6.3 ANN model for Indoor Velocity Forecasting .......................... 126
5.7 Discussion of the Findings ................................................................. 135
5.8 Chapter Summary ............................................................................ 137

CHAPTER 6 ........................................................................................................ 142
CONCLUSIONS AND RECOMMENDATIONS .............................................. 142
6.1 Introduction ......................................................................................... 142
6.2 Conclusions ...................................................................................... 142
  6.2.1 To investigate real data sets pattern for environmental parameters both indoor and outdoor at specific locations in Peninsular Malaysia ........................................................................ 143
  6.2.2 To determine the level of indoor environmental condition at the selected buildings and compare the results with recommended standards and previous research .................................. 144
  6.2.3 To develop models using ANN to predict indoor environmental parameters in four traditional Malay houses in Peninsular Malaysia ........................................................................ 145
  6.2.4 To simulate and validate the accuracy of the prediction model .. 146
6.3 Limitations of the study ..................................................................... 147
6.4 Recommendations for Future Research ........................................... 148

REFERENCES .................................................................................................. 150
APPENDIX A ................................................................................................. 163
# LIST OF TABLES

| Table 1.1: | List of Artificial Neural Network Tools | 5 |
| Table 2.1: | Standard for comfort condition | 28 |
| Table 2.2: | Comfort Ranges in Malaysia | 29 |
| Table 2.3: | Thermal Comfort Studies in Malaysia | 29 |
| Table 2.4: | ASHRAE Standard 55 – 1992 | 30 |
| Table 2.5: | ISO Standard 7730 – 1994 | 31 |
| Table 2.6: | Summary of CIBSE guide | 32 |
| Table 2.7: | MALAYSIAN Standard 1525 – 2007 | 32 |
| Table 2.8: | The scale of measurement for temperature | 33 |
| Table 2.9: | The scale of measurement for relative humidity | 34 |
| Table 2.10: | The scale of measurement for wind speed | 34 |
| Table 3.1: | Results of the network structure optimization | 38 |
| Table 3.2: | ANN structure optimization | 40 |
| Table 3.3: | Different types of transfer functions | 46 |
| Table 4.1: | Classification of the Malay traditional houses based on the zoning or regional styles | 60 |
| Table 4.2: | List of input variables and output variable | 67 |
| Table 5.1: | Air Temperature data in traditional Malay house | 81 |
| Table 5.2: | Relative humidity data in traditional Malay house | 82 |
| Table 5.3: | Air velocity data in traditional Malay house | 83 |
| Table 5.4: | Air Temperature data at Modern Contemporary building | 88 |
| Table 5.5: | Relative humidity data at Modern Contemporary building | 89 |
| Table 5.6: | Air velocity data at Modern Contemporary building | 89 |
| Table 5.7: | Air Temperature data in Modern Contemporary building | 90 |
| Table 5.8: | Relative Humidity data in Modern Contemporary building | 91 |
| Table 5.9: | Air Velocity data in Modern Contemporary building | 92 |
| Table 5.10: | Measurement results and reference standards for air temperature, relative humidity, and air velocity level in the natural ventilated and air-conditioned building | 97 |
| Table 5.11: | Results of linear regression analysis for natural ventilated and air-conditioned buildings | 102 |
| Table 5.12: | ANN Structure Optimization for Rumah Negeri Sembilan | 107 |
| Table 5.13: | ANN Structure Optimization for Istana Ampang Tinggi | 107 |
| Table 5.14: | ANN Structure Optimization for Rumah Tok Su | 107 |
Table 5.15: ANN Structure Optimization for Rumah Seri Banai .................. 107
Table 5.16: Structure and training results of ANN models for indoor temperature forecasting ......................................................... 111
Table 5.17: Results of forecast by the ANN model (3-37-1) for natural ventilated building ............................................................. 112
Table 5.18: Results of forecast by the ANN model (3-12-1) for natural ventilated building ............................................................. 112
Table 5.19: Results of forecast by the ANN model (3-30-1) for natural ventilated building ............................................................. 113
Table 5.20: Results of forecast by the ANN model (3-17-1) for natural ventilated building ............................................................. 113
Table 5.21: Results of forecast by the ANN model (3-37-1) for air-conditioned building ............................................................. 114
Table 5.22: Results of forecast by the ANN model (3-12-1) for air-conditioned building ............................................................. 114
Table 5.23: Results of forecast by the ANN model (3-30-1) for air-conditioned building ............................................................. 115
Table 5.24: Results of forecast by the ANN model (3-17-1) for air-conditioned building ............................................................. 115
Table 5.25: ANN Structure Optimization for Rumah Negeri Sembilan .......... 117
Table 5.26: ANN Structure Optimization for Istana Ampang Tinggi .......... 117
Table 5.27: ANN Structure Optimization for Rumah Tok Su ................. 117
Table 5.28: ANN Structure Optimization for Rumah Seri Banai .......... 117
Table 5.29: Structure and training results of ANN models for indoor humidity forecasting ............................................................. 121
Table 5.30: Results of forecast by the ANN model (3-40-1) for natural ventilated building ............................................................. 122
Table 5.31: Results of forecast by the ANN model (3-11-1) for natural ventilated building ............................................................. 122
Table 5.32: Results of forecast by the ANN model (3-31-1) for natural ventilated building ............................................................. 123
Table 5.33: Results of forecast by the ANN model (3-36-1) for natural ventilated building ............................................................. 123
Table 5.34: Results of forecast by the ANN model (3-40-1) for air-conditioned building ............................................................. 124
Table 5.35: Results of forecast by the ANN model (3-11-1) for air-conditioned building ............................................................. 124
Table 5.36: Results of forecast by the ANN model (3-31-1) for air-conditioned building ............................................................. 125
Table 5.37: Results of forecast by the ANN model (3-36-1) for air-conditioned building ............................................................. 125
Table 5.38: ANN Structure Optimization for Rumah Negeri Sembilan .... 127
Table 5.39: ANN Structure Optimization for Istana Ampang Tinggi ....... 127
<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 5.40</td>
<td>ANN Structure Optimization for Rumah Tok Su</td>
<td>127</td>
</tr>
<tr>
<td>Table 5.41</td>
<td>ANN Structure Optimization for Rumah Seri Banai</td>
<td>127</td>
</tr>
<tr>
<td>Table 5.42</td>
<td>Structure and training results of ANN models for indoor velocity forecasting</td>
<td>131</td>
</tr>
<tr>
<td>Table 5.43</td>
<td>Results of forecast by the ANN model (3-23-1) for natural ventilated building</td>
<td>132</td>
</tr>
<tr>
<td>Table 5.44</td>
<td>Results of forecast by the ANN model (3-30-1) for natural ventilated building</td>
<td>132</td>
</tr>
<tr>
<td>Table 5.45</td>
<td>Results of forecast by the ANN model (3-35-1) for natural ventilated building</td>
<td>133</td>
</tr>
<tr>
<td>Table 5.46</td>
<td>Results of forecast by the ANN model (3-18-1) for natural ventilated building</td>
<td>133</td>
</tr>
<tr>
<td>Table 5.47</td>
<td>Results of forecast by the ANN model (3-23-1) for air-conditioned building</td>
<td>134</td>
</tr>
<tr>
<td>Table 5.48</td>
<td>Results of forecast by the ANN model (3-30-1) for air-conditioned building</td>
<td>134</td>
</tr>
<tr>
<td>Table 5.49</td>
<td>Results of forecast by the ANN model (3-35-1) for air-conditioned building</td>
<td>135</td>
</tr>
<tr>
<td>Table 5.50</td>
<td>Results of forecast by the ANN model (3-18-1) for air-conditioned building</td>
<td>135</td>
</tr>
<tr>
<td>Table 5.51</td>
<td>ANN model, MAPE values and evaluation results for indoor temperature forecasting</td>
<td>136</td>
</tr>
<tr>
<td>Table 5.52</td>
<td>ANN model, MAPE values and evaluation results for indoor humidity forecasting</td>
<td>136</td>
</tr>
<tr>
<td>Table 5.53</td>
<td>ANN model, MAPE values and evaluation results for indoor velocity forecasting</td>
<td>136</td>
</tr>
<tr>
<td>Table 5.54</td>
<td>Overall results obtained in this research</td>
<td>138</td>
</tr>
<tr>
<td>Table 5.55</td>
<td>$R^2$ – value for natural ventilated and air-conditioned building</td>
<td>139</td>
</tr>
<tr>
<td>Table 5.56</td>
<td>Structure and training results of the neural network models</td>
<td>141</td>
</tr>
<tr>
<td>Table 5.57</td>
<td>MAPE values and evaluation results for naturally ventilated and air-conditioned buildings</td>
<td>141</td>
</tr>
<tr>
<td>Table 6.1</td>
<td>Results of linear regression analysis for naturally ventilated and air-conditioned buildings</td>
<td>145</td>
</tr>
<tr>
<td>Table 6.2</td>
<td>Best ANN models for predicting indoor environmental parameters</td>
<td>146</td>
</tr>
<tr>
<td>Table 6.3</td>
<td>Summary of the evaluation results</td>
<td>147</td>
</tr>
</tbody>
</table>
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1.1:</td>
<td>Organization of thesis Figure</td>
<td>10</td>
</tr>
<tr>
<td>Figure 2.1:</td>
<td>Map of Malaysia and South East Asian Region</td>
<td>13</td>
</tr>
<tr>
<td>Figure 2.2:</td>
<td>Map of Malaysia showing regions in Peninsular and East Malaysia</td>
<td>14</td>
</tr>
<tr>
<td>Figure 2.3:</td>
<td>Various types of Malay house; bumbung panjang (top left), bumbung lima (top right), bumbung perak (bottom left), and bumbung limas (bottom right)</td>
<td>19</td>
</tr>
<tr>
<td>Figure 2.4:</td>
<td>Section of basic traditional Malay house</td>
<td>20</td>
</tr>
<tr>
<td>Figure 2.5:</td>
<td>The Malay house as a human body</td>
<td>20</td>
</tr>
<tr>
<td>Figure 2.6:</td>
<td>Characteristics of Malay Traditional Houses uses to Response Local Climate</td>
<td>22</td>
</tr>
<tr>
<td>Figure 3.1:</td>
<td>Observed vs. predicted POPS2 by Model-1 for (a) training and (b) testing</td>
<td>39</td>
</tr>
<tr>
<td>Figure 3.2:</td>
<td>ANN predicted PIAQ vs. actual PIAQ for (a) training and (b) testing</td>
<td>40</td>
</tr>
<tr>
<td>Figure 3.3:</td>
<td>Biological and artificial neuron design, (a) A biological neuron; (b) Simple model of an artificial neuron</td>
<td>42</td>
</tr>
<tr>
<td>Figure 3.4:</td>
<td>Feed-forward (FNN) and recurrent architecture (RNN) of an artificial neural network</td>
<td>44</td>
</tr>
<tr>
<td>Figure 3.5:</td>
<td>A typical multilayer feed-forward neural network</td>
<td>45</td>
</tr>
<tr>
<td>Figure 4.1:</td>
<td>Research Methodology Flow Chart</td>
<td>59</td>
</tr>
<tr>
<td>Figure 4.2:</td>
<td>Location of case studies</td>
<td>61</td>
</tr>
<tr>
<td>Figure 4.3:</td>
<td>Hygro Thermo-Anemometer</td>
<td>62</td>
</tr>
<tr>
<td>Figure 4.4:</td>
<td>Location of measurement points at Restaurant Bisik-Bisik</td>
<td>63</td>
</tr>
<tr>
<td>Figure 4.5:</td>
<td>Location of measurement points at Rumah Negeri Sembilan</td>
<td>63</td>
</tr>
<tr>
<td>Figure 4.6:</td>
<td>Location of measurement points at Istana Ampang Tinggi</td>
<td>63</td>
</tr>
<tr>
<td>Figure 4.7:</td>
<td>Location of measurement points at Rumah Tok Su</td>
<td>64</td>
</tr>
<tr>
<td>Figure 4.8:</td>
<td>Location of measurement points at Rumah Seri Banai</td>
<td>64</td>
</tr>
<tr>
<td>Figure 4.9:</td>
<td>Location of measurement points inside and outside the building</td>
<td>66</td>
</tr>
<tr>
<td>Figure 5.1:</td>
<td>Location of the case studies (Johor, Negeri Sembilan and Kedah)</td>
<td>74</td>
</tr>
<tr>
<td>Figure 5.2:</td>
<td>Bisik – Bisik Restaurant</td>
<td>76</td>
</tr>
<tr>
<td>Figure 5.3:</td>
<td>(a) Rumah Negeri Sembilan; (b) Istana Ampang Tinggi</td>
<td>77</td>
</tr>
</tbody>
</table>
Figure 5.4: (a) Rumah Tok Su; (b) Rumah Seri Banai .......................... 78
Figure 5.5: Tunku Tun Aminah Library, UTHM................................. 79
Figure 5.6: Pattern of air temperature (a), relative humidity (b), and air
velocity (c), at five case studies area........................................... 85
Figure 5.7: Pattern of indoor air temperature (a), relative humidity (b),
and air velocity (c), at five case studies area................................. 87
Figure 5.8: Pattern of outdoor air temperature (a), relative humidity (b),
and air velocity (c), at Tunku Tun Aminah Library, UTHM.......... 94
Figure 5.9: Pattern of indoor air temperature (a), relative humidity (b),
and air velocity (c), at Tunku Tun Aminah Library, UTHM.......... 96
Figure 5.10: Relationships between outdoor conditions and indoor
conditions in the traditional Malay house (a) Air temperature;
(b) Relative humidity; (c) Air velocity.......................................... 99
Figure 5.11: Relationships between outdoor conditions and indoor
conditions in the Library, UTHM (a) Air temperature; (b)
Relative humidity; (c) Air velocity............................................. 101
Figure 5.12: Three-layered feed-forward network adopted for the
environmental parameters forecasting........................................ 104
Figure 5.13: A three-layered feed-forward neural network adopted for the
indoor temperature forecasting.................................................. 106
Figure 5.14: Training, Validation and Test errors during training; (a)
ANN4: 3-37-1, (b) ANN1: 3-12-1............................................. 109
Figure 5.15: Regression analysis between the outputs and the targets; (a)
ANN4: 3-37-1, (b) ANN1: 3-12-1............................................. 109
Figure 5.16: Training, Validation and Test errors during training; (a)
ANN1: 3-30-1; (b) ANN2: 3-17-1 ........................................... 110
Figure 5.17: Regression analysis between the outputs and the targets; (a)
ANN1: 3-30-1, (b) ANN2: 3-17-1........................................... 111
Figure 5.18: A three-layered feed-forward neural network adopted for the
indoor humidity forecasting......................................................... 116
Figure 5.19: Training, Validation and Test errors during training; (a)
ANN4: 3-40-1; (b) ANN1: 3-11-1 ........................................... 119
Figure 5.20: Regression analysis between the outputs and the targets; (a)
ANN4: 3-40-1, (b) ANN1: 3-11-1........................................... 119
Figure 5.21: Training, Validation and Test errors during training; (a)
ANN2: 3-31-1, (b) ANN4: 3-36-1........................................... 120
Figure 5.22: Regression analysis between the outputs and the targets; (a)
ANN2: 3-31-1, (b) ANN4: 3-36-1........................................... 121
Figure 5.23: A three-layered feed-forward neural network adopted for the
indoor velocity forecasting......................................................... 126
Figure 5.24: Training, Validation and Test errors during training; (a)
ANN4: 3-23-1; (b) ANN3: 3-30-1 ........................................... 129
Figure 5.25: Regression analysis between the outputs and the targets; (a) ANN4: 3-23-1, (b) ANN3: 3-30-1................................. 129

Figure 5.26: Training, Validation and Test errors during training; (a) ANN4: 3-35-1, (b) ANN1: 3-18-1............................................. 130

Figure 5.27: Regression analysis between the outputs and the targets; (a) ANN4: 3-35-1, (b) ANN1: 3-18-1................................. 131
### LIST OF SYMBOLS AND ABBREVIATIONS

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AI</td>
<td>Artificial Intelligence</td>
<td>Artificial Intelligent</td>
</tr>
<tr>
<td>ANN</td>
<td>Artificial Neural Network</td>
<td></td>
</tr>
<tr>
<td>ASHRAE</td>
<td>American Society of Heating,</td>
<td>American Society of Heating, Refrigerating and</td>
</tr>
<tr>
<td></td>
<td>Refrigerating and Air-</td>
<td>Air-Conditioning Engineers</td>
</tr>
<tr>
<td>IEQ</td>
<td>Indoor Environmental Quality</td>
<td></td>
</tr>
<tr>
<td>RH</td>
<td>Relative humidity</td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>Temperature</td>
<td></td>
</tr>
<tr>
<td>MSE</td>
<td>Mean square error</td>
<td></td>
</tr>
<tr>
<td>MAPE</td>
<td>Mean Absolute Percentage Error</td>
<td></td>
</tr>
</tbody>
</table>
# LIST OF APPENDIX

<table>
<thead>
<tr>
<th>APPENDIX</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Raw data for case study building</td>
<td>163</td>
</tr>
</tbody>
</table>
CHAPTER 1

INTRODUCTION

1.1 Background of the Research

“Indoor” refers to the environments inside homes, schools, public buildings, and similar spaces to which the public has access (National Research Council, 1981). In recent years, the issue of indoor environmental condition in building has received great attention. Global warming and rapid development in building and construction industry added the increasing of environmental condition issue. The main reason was because of people typically spend most of their times in the indoor environment compared to the external environment which implies that the indoor environment has become more important to the public health.

Nowadays, people are demanding on their quality of life. In order to sustain the quality of life, healthy, safe and comfortable indoor environments are needed. A quality indoor environment is one which promotes comfort, health, and well-being of the building occupancy. Building exist to protect people from the elements and to otherwise support human activity. However, unless buildings are managed well, indoor environmental conditions have the potential to make people sick, cause them discomfort, or otherwise inhibit their ability to perform.
A building is a system that is linked to its surrounding environment and is subject to a range of interactions between the external conditions and the indoor comfort condition (Naseer, 2013). To create a comfortable indoor climate, architects and engineers should have to take decisions from the beginning of the design process (Malinda Anthony, 2002).

A good building design will contribute to a good quality of living space. Hanafi (1999) stated that traditional building design deliver good indoor comfort and suitable with local climate. It is often regarded as a good natural ventilated dwelling in hot humid climate due to its design strategies and material selection (Mohd Hafizal et al., 2012). It can be described as raised on timber stilts with floor and wall gaps to allow maximum cross ventilation (Mohd Hafizal et al., 2012) and made of materials which were easily available from the tropical forests such as timber, bamboo, rattan and leaves (Wafi and Ismail, 2008). However, the local building materials and the coherent design principles of the traditional forms are being abandoned under the influence of modernism.

According to Hanafi (1999), the traditional concept of the building had been displaced with modern design which incorporates architectural styles and materials that ignore the local climatic conditions as well as the cultural, social and economic interactions. It has been modified to adapt with new materials for their durability such as concrete and bricks for walls; metal, concrete and clay tiles for roofing in several types, colours and styles. In fact most of imported building technologies are not thermally suitable under Malaysian climate (Wafi and Ismail, 2008). Consequently, such buildings will end up with poor indoor climate, which affects comfort, health and efficiency. The problem is found in dwellings as well as workplaces or public buildings, such as schools and hospitals.

The location of Malaysia which is under tropical climate region is naturally hot and a humid climate. According to Rajapaksha et al. (2003), local climate greatly affects the indoor thermal environment in buildings. Buildings are overheated during the day due to solar heat gain through the building envelope and solar penetration through windows. Ahmed (2003) stated that comfortable outdoor spaces have a significant bearing on the comfort perception of the indoor ambience. Therefore, the demand for comfort conditions in buildings is significantly increased as a result of exposure to uncomfortable outdoors. In the context of Malaysia,
overheated outdoor environment of the city has contributed to a growing preference for a lower comfort temperature indoors. Considering this situation, a large number of the buildings are served by air-conditioning units and other mechanical ventilation systems that are designed to maintain a thermally comfortable indoor environment (Wafi and Ismail, 2008; Khalil and Husin, 2009). This in turn has put an immense pressure on the energy demand in the cities. This situation contributes to the excessively high amount of energy consumption for cooling as well as its running cost. Besides that, it also will have a negative impact on the environment.

Climate is a principal physical environment factor in the design of buildings and settlement for the indoor environment comfort condition. According to Manibhai (2013), the climate of a region plays a great role in determining the design and construction of a building because the indoor environment is strongly influenced by the impacts of outdoor environment. Conducive spatial and indoor environments are major aspects in the successful performance in a building. Both human beings and buildings interact with heat, light, sound, air, and other climatic and geophysical elements that surround them and they contribute to the formation of comfort condition. Besides that, the external factors directly influence the indoor climate in many buildings. Hence, outdoor overall planning requires to be considered in order to identify factors that encourage the formation of an acceptable indoor fresh air flow into the building. Therefore, in order to design a structure responding to environment all factors that effect on the external environment as well as aspects of internal environment should be considered (Lavafpour and Surat, 2011).

The creation of comfortable, healthy and safe environments with the most efficient of energy consumption is fundamental to the successful operation of a building. These requirements are of greater importance as concern grows over both the qualities of indoor climate and the global impact of energy use. Considering both the severe global environmental situation brought by high energy consumption and the environmental quality needs from building occupants, the concept that to achieve better environmental quality, higher performance and more sustainable building by exploring climatic conditions and environmental strategies in the conventional vernacular building form has been put forward and got wider recognition (Olgyay and Olgyay, 1963; Givoni, 1998; SHI and Edward, 2014). The concept has been known as climatic design, a method for reducing overall energy cost of a building
(Lin and Deng, 2008; Shakoor, 2011). Climatic design creates comfortable, energy efficient and environmentally wise buildings. Besides that, it can be learned and stimulated by observation and prediction.

Classical process-based modelling approaches can provide good estimations of indoor environment, but they usually are too general to be applied directly without a lengthy data calibration process. They often require approximations of various processes, and these approximations may overlook some important factors affecting the processes within the environment. According to Palani et al., (2008) a process based model requires a lot of input data and model parameters that are often unknown, while data driven techniques provide an effective alternative to conventional process-based modelling. Moreover, this models developed by data-driven techniques are expected to be computationally very fast and require fewer input parameters than process-based models.

Data-driven modelling techniques have gained popularity in the last several years. The scientific and engineering communities have acquired already extensive experience in the development and usage of data-driven techniques. One of the most popular data-driven approaches is Artificial Neural Network (ANN). ANN is as simplified mathematical models of brain-like systems (Hassan and Li, 2010).

ANN often offers a superior alternative to traditional physical-based models, and excels at understanding the behaviour of patterns or relationships in data. It is also a powerful non-linear estimator which is recommended when the functional form between input and output is unknown or it is not well understood but believed to be nonlinear (Salazar et al., 2007). This is especially the case in providing comfortable indoor environment where the factors influencing indoor comfort condition are highly interactive. These considerations justify the use of ANN modeling approach. Moreover, as an artificial intelligent (AI) information-processing tool, the ANN system has been proven to be a powerful approach to solving complex nonlinear mappings with higher accuracy than regression methods.

There are available numerous software tools to design and manage the ANN. However, only a few of them were used in papers more often than the others. Among of them, MATLAB was successfully used in several works including Strik et al., (2005); Sofuoglu (2008); Al-Shamisi et al., (2011) and Sapon et al., (2011). Therefore, the MATLAB Neural Network Toolbox was used in this study because it
is flexible and easy to apply. The list of available software mentioned is presented in Table 1.1.

Table 1.1: List of Artificial Neural Network Tools (Source: Krenek et al., 2014)

<table>
<thead>
<tr>
<th>Tool name</th>
<th>Environment</th>
<th>License</th>
</tr>
</thead>
<tbody>
<tr>
<td>NeuroShell 2</td>
<td>SA</td>
<td>Commercial</td>
</tr>
<tr>
<td>Weka</td>
<td>SA</td>
<td>GNU GPL</td>
</tr>
<tr>
<td>Neural Network Toolbox</td>
<td>MATLAB</td>
<td>Commercial</td>
</tr>
<tr>
<td>NeuroXL</td>
<td>MS Excel</td>
<td>Commercial</td>
</tr>
</tbody>
</table>

The use of artificial neural networks (ANN) is a new promising approach to simulate engineering problems (Sharma et al., 2000; Ramli, 2011). It has been shown to be a powerful and versatile tool, particularly in dealing with prediction and classification problems. Besides that, ANN has been utilized in various building applications such as prediction of heating load, ventilation rate and indoor temperature. Therefore, primary interest of this study is to analyze environmental parameters within both naturally ventilated and air-conditioned buildings and to construct predictive models by using the ANN technique.

1.2 Problem Statement

Malaysia as warm and humid tropical climate is known by its characteristics of high temperatures, high relative humidity and very low wind speeds. Under these weather conditions, these for sure make the environment conditions uncomfortable in building. In view of this, it is important to study the indoor environment especially thermal environment. Therefore, it is important to conduct this study to get all the parameters needed in developing the indoor environment prediction model and to propose indoor environment prediction with improvement of indoor environment statistical model.

There are many prediction models that have been developed to forecast environment condition within building. However, there has been no research purposely done on the forecast of indoor environmental parameters model based on
ANN. In this study, with the aid of ANN which is one of data driven modeling techniques, indoor environmental parameters prediction model will be developed and the advantages of using ANN for forecasting will be identified.

1.3 Aims and Objectives of the Research

The aim of this research is to develop prediction model using Artificial Neural Networks (ANN) technique to predict indoor environmental parameters in natural ventilated building in Malaysia. To achieve this aim, the following objectives have been identified and carried out:

i. To investigate real data sets pattern for environmental parameters both indoor and outdoor at a specific locations in Peninsular Malaysia.
ii. To determine the level of indoor environmental condition at the selected buildings and compare the results with recommended standards and previous research.
iii. To develop models using ANN to predict indoor environmental parameters in four traditional Malay houses in Peninsular Malaysia.
iv. To simulate and validate the accuracy of the prediction model.

1.4 Scopes and Limitations of the Research

The scope of research falls into two broad sections, that is, environmental parameters measure including air temperature, relative humidity and air velocity at both natural ventilated and air-conditioned buildings through selected case study; and forecasting models of indoor environmental parameters.

For the first section, a comprehensive literature review on the issues of the indoor environment was conducted. Through this review, a better understanding on the theoretical aspect of the study can be achieved. Three locations were identified
as suitable case study area which is located at Johor, Negeri Sembilan and Kedah. In order to develop the prediction model, data for all parameters considered for the study area need to be identified and it will be collected using anemometer.

In developing forecasting models of indoor environmental parameters, a literature review on theory and application of artificial neural networks serves as a prelude to develop the ANN models. The prediction model will be developed by using MATLAB Neural Network Toolbox software.

Both field measurement and application of MATLAB software are used in a complementing manner in the investigations of indoor environment condition as part of the methodology employed in this research, and thus bears the limitations of the toolbox used.

1.5 Significance of the Research

This study is beneficial because it can provide baseline information and advancement of knowledge and design appropriate within tropical climate for best indoor environmental condition for the future building design. Moreover, data such as temperature distribution and wind speed can be used as a guideline by relevant government bodies, houses developers and agencies to come up with more energy conserving building design. Through this study also, it is expected lesson can be drawn from the climatic design of traditional house for the future building design in the modern context.

From a comprehensive research finding output, a Neural Network Model developed. The developed application hopefully will be a potential application to forecast environment condition within building at any given time and also can be used to supplement measurements, or to predict impacts when measurements cannot be made. Besides that, with the aid of the prediction model also helps the engineers to formulate strategies and mitigation measured for minimizing the energy consumption within building.
1.6 Organization of the Thesis

This thesis is organized into six chapters. A brief introduction to the overall thesis and its contents are presented in this chapter identified as chapter one. This chapter introduces the main issue of this research, discusses the research background, problem statements, objectives, scope and limitations of the research, significance of the research and the overall research structure. A brief summary of another chapter are outlined below:

Chapter two reviews the background studies or related literature that directly influences our general understanding of the area of concern. It begins with a review on climate condition and vernacular architecture in Malaysia. Following that is a review on fundamental concept of indoor environmental condition focusing on thermal comfort study for Malaysia. It discusses briefly the factors affecting comfort and criteria for thermal comfort in Malaysia. Additionally, overview on the existing practice in indoor environmental condition for Malaysia is also presented. The procedures involved and problems occurred will be discussed in details. This chapter concludes with discussion on some of the common research methods and experimental procedures for indoor environment prediction studies employed by previous researchers. Thus, in general, this chapter can best be described as the literature review which constitutes the background study of the whole thesis.

Chapter three outlines briefly the background of Artificial Neural Network (ANN) and its capabilities. Every component in the neural network structure is discussed and the procedure involved in developing and operating a neural network will be reviewed. Next, information regarding MATLAB Neural Network Toolbox software used for this research is explained. Briefly, this chapter sets out the guidelines for the implementation of the neural network model.

Chapter four outlines the research design and methodology in detail including data collection method, type of data collected and the method of data analysis to be employed. This chapter will be divided into two main parts; measurements of environmental parameters and methodology of ANN. The method of measurement is discussed thoroughly. As for the ANN, the discussion will be focused on every stage of the ANN development. It starts from the development of ANN structure, followed by the process involved which include training process, testing and finally
validation phase. Finally, the data analyses criterions are discussed, which is used to analyze the results of the experiment. Thorough analyses of the raw data collected from each type of study are discussed in the following chapter.

Chapter five presents the results from the field measurement in both natural ventilated and air-conditioned buildings in Malaysia. The field study is to gain better understanding of the relationship between outdoor and indoor climate condition and to obtain measurement data for the validation of indoor environment modelling using MATLAB software. This chapter also explains the equipment used and the experimental procedures for the field study. The implementation of the neural network model was also presented in this chapter. It focuses on the findings, analysis, and results from the application of ANN in indoor environmental parameters prediction.

Chapter six gives conclusions and highlights important findings of the research. All findings should be concluded and answer each of the objectives as been outlined in section 1.3. Further recommendations were included to improve the research for future development.
<table>
<thead>
<tr>
<th>Chapter 1: Introduction</th>
<th>Chapter 2: Vernacular Architecture and Indoor Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Brief background</td>
<td>• Review of climate condition in Malaysia, characteristics of Malay Traditional Architecture, criteria for indoor comfort condition, standard and guidelines.</td>
</tr>
<tr>
<td>• Research objectives and scope of work</td>
<td>• Issue of indoor environment comfort in Malaysia.</td>
</tr>
<tr>
<td>• Significance of the research</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter 3: Artificial Neural Networks: Theory and Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Review of the background of ANN, structure and procedure involved in developing and operating a neural network.</td>
</tr>
<tr>
<td>• Selection of neural network for use in research</td>
</tr>
<tr>
<td>• Sets out guidelines for the training of the model</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter 4: Research Methodology</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Data collection</td>
</tr>
<tr>
<td>• ANN model development</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter 5: Results and Discussions</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Description of case studies building</td>
</tr>
<tr>
<td>• Results, data analysis and findings</td>
</tr>
<tr>
<td>• Step-by-step procedure for the development of the prediction models</td>
</tr>
<tr>
<td>• Analysis and findings from the application of ANN in indoor environmental parameters prediction.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter 6: Conclusions and Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Concludes the whole study with significant findings</td>
</tr>
<tr>
<td>• Gives further recommendations</td>
</tr>
</tbody>
</table>

Figure 1.1: Organization of thesis Figure
1.7 Chapter Summary

This chapter has laid the foundation of the thesis. It has introduced the research problem. The background of the Malaysian conditions has been described, the methodological approach has been introduced, the limitations have been identified, and the format of the report has been outlined. On this foundation, this thesis can proceed with a detailed description of the research.
CHAPTER 2

VERNACULAR ARCHITECTURE AND INDOOR ENVIRONMENT

2.1 Introduction

This is the early stage and an important part of the research. A literature review was carried out to establish some knowledge of the research topic. Through the literature review, a clear framework of the research was established and helped to start the research easily. This chapter briefly discusses the matters related to the indoor environment. It begins with a review on climate condition and vernacular architecture in Malaysia. Following that is a review on fundamental concepts of indoor environmental condition focusing on thermal comfort study for Malaysia. It discusses briefly the factors affecting comfort and criteria for thermal comfort in Malaysia. Additionally, overview on the existing practice in indoor environmental condition for Malaysia is also presented. The procedures involved and problems occurred will be discussed in detail. This chapter concludes with discussion on some of the common research methods and experimental procedures for indoor environment studies employed by previous researchers.
2.2 General Characteristics of the Hot Humid Climate of Malaysia

Malaysia is made up of two main continents namely the Peninsular Malaysia and 2 states on the northern side of Borneo, Sabah and Sarawak. It is situated in central Southeast Asia, bordering on Thailand in the north, with Singapore and Indonesia to the south and the Philippines to the east, at latitudes between 1° and 7° North of the Equator and longitudes of between 100° and 119° East (Abdullah, 2007), as illustrated in Figure 2.1.

According to Gulam Hassan and Golam Hassan (2003), the regions in Malaysia are divided into six regions. There are four regions in Peninsular Malaysia (West Malaysia), and two regions in North Borneo (East Malaysia) as illustrated in Figure 2.2. The four regions in Peninsular Malaysia are the northern region (Perlis, Kedah, Perak and Pulau Pinang), the central region (Selangor, Federal Territory of Kuala Lumpur, Negeri Sembilan, and Melaka), the eastern region (Kelantan, Terengganu and Pahang), and the southern region, which consists of just one state, Johor. The two regions in East Malaysia are the Sabah region, which consists of Sabah, and the Sarawak region, which consists of Sarawak.
Malaysia can be classified as having a warm or hot humid climate. Since its location is in close proximity to the equator, the sun rays are always overhead all the year round. For most parts of the country, the sunniest period of the year occurs during the months of February and March at the end of Northeast Monsoon. In the Northwest, February is the sunniest month with an average of 8.5 hours per day. In the south and central areas, the hottest days are between the months of March to April, while on the East Coast they are between March and April (Abdullah, 2007).

The climate of Malaysia is not subjected to great extreme of temperature. This is mainly due to its insularity and moderate relief. All parts are within 80 miles of the sea and the entire country is permanently bathed in warm moist tropical maritime air. In general, it may be said that the temperature seldom rises above 36°C or falls below 20°C. The temperatures are high all the year round with the annual mean varying between 1 – 3°C of the mean shade air temperature of 27°C. The annual mean diurnal range is less than 7°C, whilst the monthly mean diurnal range is only 12°C. The average annual mean relative humidity is 85%. By day it varies between 55% and 70%, and at night it rises above 90% which often makes evaporation and sleeping difficult. Since the temperature of Malaysia is uniformly high all the year round, there is no alternation between summer and winter as in temperate regions. There is no wet or dry season. Heavy rainfall may be experienced anywhere at any time of the year, and whilst short dry spells sometimes
occurs, they are normally not long enough to be called a dry season (Abdullah, 2007).

The wind is the most important climatic element which determines the seasons of Malaysia. Changes in the direction and speed of air streams that cross the Peninsular are responsible for the division of the year into four monsoons. The four monsoon seasons, which are affected by the wind, determine the general pattern of rainfall but it varies from place to place. One remarkable feature of the distribution of rainfall in the Peninsular is the way in which it varies considerably between places only a short distance apart and without the intervening highlands. The four monsoon seasons are as follows: (Abdullah, 2007)

i. *Northeast Monsoon Season* – Northeasterly wind blowing from South China Sea sweeps over the country, bringing a lot of rainfall on the East Coast, which is the highest in December and may cause flooding in many coastal areas of Kelantan, Terengganu and Pahang. The speed of the wind seldom exceeds 10.7 m/s, except during occasional tropical storm accompanying the heavy showers which prevail from November until March.

ii. *Inter – Monsoon or Transitional period* – The period of five to seven weeks in the month of April in the south and May in the north. During this short period, the winds are either weak and variable or reduced to calm.

iii. *Southwest Monsoon Season* – Southwesterly trade winds from the Indian Ocean blow into the West Coast of the Peninsular in May and June and bring light rain.

iv. *Second Transitional Season* – This occurs after the Southwest Monsoon in October and early November and brings a lot of rain into the West Coast regions. The wind is weak and variable with a high percentage of calm periods.
2.3 Vernacular Architecture

Vernacular come from the Latin word which is ‘Verna’, a slave and the connotations still exist in Italy, even though ‘vernaculus’ meant ‘native’. Oliver (2006) in his book *Built to Meet Needs* has defined vernacular as:

‘Vernacular architecture comprises the dwellings and all other buildings of the people. Related to their environmental contexts and available resources, they are customarily owner or community-built, utilizing traditional technologies. All forms of vernacular architecture are built to meet specific needs, accommodating the values, economies and ways of living of the cultures that produce them’.

According to Krisprantono (2005), vernacular building pursues the relationship between the theoretical and practical knowledge that covers the physical and non-physical characteristics of a particular location or place. The physical character refers to the knowledge that is connected with human versus nature, in term of appropriate responses to environmental factors such as the variation of climate, topography and the limitation of the materials. The non-physical character refers to culture and technology, social relationship and history of the people. Furthermore, he emphasizes that vernacular building expresses the specific nature of the specific cultures and can employ numerous forms that symbolize the relationship between humans, society and the natural and built environments they live in.

Vernacular architecture is a term used to categorize methods of construction which use locally available resources to address the local needs (Helena, 1998; Singh et al., 2010). These kinds of buildings are constructed using locally available materials and shows a greater respect to the existing environment and also takes into account the constraints imposed by the climate (Gallo, 1994; Singh et al., 2010). These kinds of structure evolve over time to reflect the environmental, cultural and historical context in which they exist (Helena, 1998; Singh et al., 2009).

Vernacular buildings, either individually or a whole settlement, are the best examples of the harmony among human behavior, building and the natural environment. In contrast to modern buildings, vernacular architecture in any region is more adaptable to the environment in many ways. Traditionally, builders used
knowledge passed from generation to generation to ensure that their buildings could modify the impact of a hostile outdoor environment (Sundarraja and Radhakrishnan, 2009). It may not possess the grandeur or ostentatiousness found in modern buildings designed by modern self-conscious designers but it reflects other qualities lacking in the modern buildings – a clear expression of the way of life and culture of its users.

2.3.1 Malay Traditional Architecture

‘A region can often be clearly recognized by the character of its housing….House design reflects critical factors such as climate, materials, economics and cultural background’ (Bajracharya et al., 2003). Ismail and Ahmad (2006) states that the traditional Malay house can be classified as a vernacular architecture, is the architecture of the local people, ‘architecture without architect’, of the Malay Peninsula before the colonialism period. According to Yuan (1987), the Malay house is basically a timber house with a post and lintel structure raised on stilts, with wooden, bamboo, or thatched walls and a thatched roof, the house is designed to suit the tropical climate. Ramli et al., (2012) define traditional Malay house as a house that were built by local carpenters, using local materials, own and inhabiting by the Malay people, built with deep understanding of local climate, reflect the Malay culture and religion also practice the Malay manners and heritage.

The traditional Malay house is a fine example of Malaysian vernacular architecture (Chen, 1998). It is an excellent ventilated building and extremely well designed to suit the warm and humid Malaysian climate (Tahir et al., 2010). Besides that, the Malay house created nearly perfect solution to control of climate, multifunctional use of space, flexibility in design and sophisticated prefabricated system which can extend with the growing needs of family (Yuan, 1987; Ismail and Ahmad, 2006; Hidayat, 2012). It is also identifying through riches cultural building components and decorative elements which have meanings that make uniqueness which could be the strongest features. This house, mostly spread in central Sumatera
and Malaysian Peninsular, is not just a living house. It is a part origin of people spirit in community and conception of human soul (Waterson, 2009; Hidayat, 2012).

The traditional Malay house was designed with deep understanding and respect to nature. It builds closed to sea shore or river side in hinterland area which usually as compound formation that sprawl to each other (Hidayat, 2012). Early Malay houses can be described as raised on timber stilts and made of materials which were easily available from the tropical forests such as timber, bamboo, rattan, tree roots and leaves. Usually the houses have pitched roofs, verandahs or porches in front, high ceilings and lots of big openings for ventilation purposes. Although these characteristics are particularly common in all Malay houses throughout the Peninsular Malaysia, their shapes and sizes differ from state to state.

2.3.2 Characteristics of Malay Traditional Architecture

The vernacular house of Malays known as Traditional Malay house evolved along different lines in the various regions and states. There were various traditional Malay house forms which can be found in Peninsular Malaysia. Each state has main characteristic, which vary from state to state. Normally, they classified based on the shapes or roof. According to Ju et al., (2012), the roof is the most prominent visual feature of the traditional Malay house. Most architectural studies have categorized traditional Malay houses according to their roof form type. There are mainly four types of roof form in traditional Malay houses which called *bumbung panjang*, *bumbung lima*, *bumbung perak* and *bumbung limas*. Referring to Sim (2010), the *bumbung lima* and *bumbung perak* houses appear to show foreign qualities that are identified as Dutch and British. The *bumbung lima*, or “five ridged roof” is influenced by European house styles of the colonial period. Diagrams of each roof form are shown in Figure 2.3.
According to Abd Rashid and Dawa (2005), the Malay traditional houses are categorized as East Coast style, Melaka style, Perak style and Kedah style that was based upon traditional geographical settlement patterns. This pattern is concerned with different coastal and riverine regions. Besides that, the Malay traditional houses also classified into zoning or regional styles and were based upon influence from migration patterns. Perlis, Kedah, Pahang and North Perak were considering as North West style. South Perak, West Pahang, Selangor, Negeri Sembilan and Melaka are known as the central western style. In addition, Kelantan, Terengganu and North Pahang are known as the East Coast style, and lastly South East Pahang and Johor as Southern style.

According to Shah (1988), the traditional Malay houses generally built according to a clear pattern and order. A basic traditional Malay house has a
verandah ‘selasar’ or ‘serambi’, a main room ‘rumah ibu’ containing a sleeping area and the kitchen ‘dapor’ at the back of the house. Referring to Teh (1994), it has been mentioned that the Johor-Bugisnese assumed that the traditional Malay house resembles or a representation of cosmic man. Figure 2.4 and Figure 2.5 shows the section of basic traditional Malay house and the Malay house as a human body.

![Figure 2.4: Section of basic traditional Malay house](Source: Ismail and Ahmad, 2006)

![Figure 2.5: The Malay house as a human body](Source: Ismail and Ahmad, 2006)

This believed might be the explanation for the reason of why the traditional Malay house is always symmetrical in design and highly decorated on the façade treatment. The most decorated part of the house is the front that is on the serambi.
Human is very much symmetrical in nature with two eyes, nose, mouth, two legs and hands. The universe has become the source of reference for decorative motives, includes plants, patterns, animals and so on. The concept of anthropomorphism, the underlying belief system of the Malays, gives the characteristics to the architecture of traditional Malay house (Ariffin, 2001; Ismail and Ahmad, 2006).

According to Yuan (1987), the Malay house is usually a well-ventilated detached building of timber structure with raised floor. It can be seen mostly in rural villages. Its climatic adaptation techniques were described as follows:

i. Raised-on-stilts lightweight construction (with open under floor space) using low thermal conductivity materials such as timber and thatch.

ii. Having full-height operable windows, upper ventilation grilles and minimal internal partitions for adequate cross ventilation.

iii. Having large roof eaves and low walls to control direct solar radiation and protect against rain.

iv. Arranged sparsely with adequate natural vegetation in the surroundings for the shade and a cooler microclimate.

The Malay house was designed and built taking these points much into account. As a result, it is a very appropriate house form suited specifically to the warm and humid Malaysian climate. Indeed, it is much more suited to the local climate compared to the modern Western-style brick house. According to Tahir et al., (2010), in the traditional Malay house, there is a clear definition of architectural elements and can be categorized into three main zones which is the top zone, which covers the roof element, the middle zone for the wall and the bottom zone which is the floor. The climatic design of the Malay house was shown in Figure 2.6.
The traditional Malay houses are bamboo or timber houses raised on stilts (timber) which it is basically used lightweight construction of wood and other natural materials to cater the local climate. The building mostly is a post and lintel structure with timber or bamboo walls and a thatched gabled shape roof. The lightweight construction of the house with minimum mass and many voids, using low-thermal-capacity and high-insulation materials, is the most appropriate for thermal comfort in Malaysian climate because it holds little heat and cools adequately at night.

According to Lakawa (2011), the wooden traditional Malay house raised on stilts exhibits a quality of openness which is unseen in most modern houses. This is shown by the many voids of the building in its windows, ventilation grilles and panels; the open stilted bottom; and its open interiors with minimum partitions. This quality of openness reflects the importance given to ventilation in the design of Malay house.

There are numerous features in the traditional Malay house that are geared towards providing effective ventilation. The house is raised on stilts to catch winds of a higher velocity. The elongated structure of the house with minimal partitions in the interior, allows easy passage of air and cross-ventilation. Windows are plentiful.
in the house and since the body level is the most vital area for ventilation, full-length fully openable windows are used. Besides ensuring adequate ventilation in the interior of the house, winds from the exterior are also encouraged to flow through the house. The random arrangement of the kampong houses and the careful planting and selection of trees ensure that winds are not blocked for the houses in the latter path of the wind (Yuan, 1987).

In a hot and humid climate, the roofing system plays a crucial role in keeping the rainwater from entering the house. Usually, traditional houses in Southeast Asia have a pitch roof. The steeper the roof slope, the quicker the rainwater runs down through the slope (Hassan, 2001). The roof in traditional Malay house basically comes from attap which have good insulating properties and it retain or conduct little heat into the building (Yuan, 1987). Attap is thatch made from nipah (palm type leaves), one type of palm tree species found in the mangrove swamp areas (Nasir and Wan Teh, 1996). Besides that, the roof spaces are properly ventilated by the provision of ventilation joints and panels in the roof construction (Yuan, 1987).

The Malay house is also designed to control direct exposure to heat from direct sunlight. Traditionally, many Malay houses are oriented to face Mecca for religious reasons. This East-West orientation of the house reduces the exposure of the house to direct solar radiation. The compound of the house is also often heavily shaded with trees and covered with vegetation. This sets the house in a cooler environment, by the trees and vegetation not absorbing and storing heat from solar radiation and reradiating it into the environment (Yuan, 1987).

It can be seen that the traditional Malay houses uses mainly ventilation and solar radiation control devices to provide climatic comfort for the house. These are the most effective means for climatic comfort in a house in the warm and humid Malaysian climate.

### 2.4 Indoor Environmental Quality (IEQ)

Recently, the concern about indoor environmental quality (IEQ) enhanced slightly among the people or public society. Therefore, buildings are increasingly design and
proposed to be “sustainable” or “green” in order to provide better indoor environmental quality to residential. Indoor environment is a central to public health because occupant spent more of their time there.

IEQ is a generic term used to describe the attributes of enclosed spaces, including the thermal, acoustic and visual environment, as well as indoor air quality (IAQ). Both physical (measurable) and perceptual (human comfort) factors play a key role in defining IEQ (Paevere et al., 2008; Hellsing, 2009). Referring to Bluyssen (2009), thermal comfort, lighting quality, acoustical quality and air quality are the important factors of IEQ. The IEQ in a building may have an influence the health, well being and comfort of building occupants, which in turn may impact on their productivity at work (Paevere et al., 2008; Hellsing, 2009).

Maintaining a healthy and comfortable indoor environment in any building requires integrating many components. According to Zakaria (2007), there are several components which have been quantified by Department of Building Service Engineering of Hong Kong Polytechnic University:

- Indoor air quality which refers to the levels of freshness, health and comfort, and related sensory immunity to any chemical or toxicological effects of compounds within the air;
- Ventilation which facilitates the naturally occurring ventilation and exhausts stale air;
- Thermal comfort which refers to several aspects such as temperature, air velocity, humidity and insulation;
- Noise which relates to unwanted sounds from outside or inside that can disturb human life, or to sounds caused by vibration; and
- Lighting comfort that indicates the fenestration, the luminance, the luminance ratio, as well as, the reflection and colour factors.

These various factors have slowly become incorporated within the building process through environmental design. In fact, historically, these parameters received the most attention when designing a building (Bluyssen, 2009).
REFERENCES


