OCCUPANT’S INDOOR COMFORT PERCEPTIONS THROUGH THERMAL, VISUAL & ACOUSTIC ASSESSMENTS IN TYPICAL MULTI-STOREY HOSTELS IN MALAYSIA

A thesis submitted to the Cardiff University in fulfillment of the requirement for the degree of
Doctor of Philosophy

By,

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May 2009
DECLARATION

This work has not previously been accepted in substance for any degree and is not concurrently submitted in candidature for any degree.

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Dedications

This thesis is dedicated to:

My beloved family

Thank you very much for all your love, sacrifice and patience.
Abstract

This study focuses on assessing the effects of the indoor climate on student occupants in typical multi-storey hostels in Malaysia through objective, subjective and evidence based prioritisation measurements. The objective measurements consisted of operative temperature; daylight ratio; luminance and sound pressure level. The subjective measurements were sampled from the student occupants' thermal, visual, acoustic and overall indoor comfort votes. The prioritisation measurement using Multiple Linear Regression and Friedman Tests assessed the relationship between physical indoor thermal, visual and acoustic conditions and students' overall indoor comfort perception vote. The investigations were conducted throughout a two month period starting from 12th May until 3rd July 2007. The hostels selected were namely, Twelfth Residential College, Universiti Malaya (H1); Eleventh Residential College, Universiti Putra Malaysia (H2); and Murni Student Apartment, Universiti Tenaga Nasional (H3). These hostels were located in the Klang Valley district.

In general, the findings showed that despite the temperature, daylight ratio and sound pressure level differences recorded in the objective measurement, the subjective surveys showed almost identical thermal, visual and acoustic comfort perception votes (i.e.: within the neutral vote category) regardless of the room location (i.e.: floor level and orientations) in each hostel. However, comparison between thermal comfort responses from student occupants in different hostels showed that occupants staying in shaded rooms (in H1) were slightly cooler than the ones staying in un-shaded rooms (in H2 and H3). There was a corresponding different in temperature of 3°C between the un-shaded and shaded rooms.
## Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acknowledgement</td>
<td>i</td>
</tr>
<tr>
<td>Dedication</td>
<td>ii</td>
</tr>
<tr>
<td>Abstract</td>
<td>iii</td>
</tr>
<tr>
<td>Contents</td>
<td>v</td>
</tr>
<tr>
<td>List of Tables</td>
<td>x</td>
</tr>
<tr>
<td>List of Figures</td>
<td>xiii</td>
</tr>
<tr>
<td>List of Plates</td>
<td>xvi</td>
</tr>
<tr>
<td><strong>1.0 INTRODUCTION</strong></td>
<td></td>
</tr>
<tr>
<td>1.1 Background</td>
<td>1-1</td>
</tr>
<tr>
<td>1.2 Case study building characteristics</td>
<td>1-4</td>
</tr>
<tr>
<td>1.3 Scope and limitation of research</td>
<td>1-6</td>
</tr>
<tr>
<td>1.4 Hypotheses and Research Questions</td>
<td>1-8</td>
</tr>
<tr>
<td>1.5 Research flow</td>
<td>1-9</td>
</tr>
<tr>
<td>Summary</td>
<td>1-10</td>
</tr>
<tr>
<td><strong>2.0 REVIEW OF FUNDAMENTAL THEORIES ON INDOOR CLIMATE &amp; COMFORT PERCEPTIONS</strong></td>
<td></td>
</tr>
<tr>
<td>2.1 Introduction</td>
<td>2-1</td>
</tr>
<tr>
<td>2.2 Review of indoor comfort factors</td>
<td>2-1</td>
</tr>
<tr>
<td>2.2.1 Thermal condition and comfort perception: models and theories</td>
<td>2-1</td>
</tr>
<tr>
<td>2.2.1.1 Heat Balance Theory</td>
<td>2-2</td>
</tr>
<tr>
<td>2.2.1.2 Measuring operative temperature</td>
<td>2-3</td>
</tr>
<tr>
<td>2.2.1.3 Analytical thermal comfort models</td>
<td>2-5</td>
</tr>
<tr>
<td>2.2.1.4 Adaptive Theory</td>
<td>2-7</td>
</tr>
<tr>
<td>2.2.2 Visual condition and perception: models and theories</td>
<td>2-9</td>
</tr>
<tr>
<td>2.2.2.1 Why use daylighting?</td>
<td>2-10</td>
</tr>
<tr>
<td>2.2.2.2 Daylight Ratio measurement</td>
<td>2-11</td>
</tr>
<tr>
<td>2.2.2.3 Source of Daylighting</td>
<td>2-13</td>
</tr>
<tr>
<td>2.2.3 Acoustics condition and perception: models and theories</td>
<td>2-16</td>
</tr>
<tr>
<td>2.2.3.1 Decibels</td>
<td>2-19</td>
</tr>
<tr>
<td>2.2.3.2 Weighting networks and equivalent level</td>
<td>2-19</td>
</tr>
<tr>
<td>2.2.3.3 Sound propagation</td>
<td>2-20</td>
</tr>
<tr>
<td>2.3 Design features of passive energy building</td>
<td>2-23</td>
</tr>
<tr>
<td>Section</td>
<td>Title</td>
</tr>
<tr>
<td>---------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>2.3.1</td>
<td>Building orientation</td>
</tr>
<tr>
<td>2.3.2</td>
<td>Room reflectance for optimise daylighting usage</td>
</tr>
<tr>
<td>2.3.3</td>
<td>Window design features</td>
</tr>
<tr>
<td>2.3.4</td>
<td>Issues of building material usage in Malaysia</td>
</tr>
<tr>
<td>2.3.5</td>
<td>Balcony design potentials</td>
</tr>
<tr>
<td>2.4</td>
<td>Influences of architectural features on occupants’ indoor comfort</td>
</tr>
<tr>
<td></td>
<td>perceptions</td>
</tr>
<tr>
<td>2.4.1</td>
<td>Architectural systems approach</td>
</tr>
<tr>
<td>2.4.2</td>
<td>Occupant’s behaviour in buildings</td>
</tr>
<tr>
<td>Summary of Review</td>
<td></td>
</tr>
<tr>
<td>Summary of Chapter</td>
<td></td>
</tr>
<tr>
<td>3.0</td>
<td>REVIEW OF INDOOR COMFORT POTENTIALS</td>
</tr>
<tr>
<td>3.1</td>
<td>Introduction</td>
</tr>
<tr>
<td>3.2</td>
<td>Thermal comfort</td>
</tr>
<tr>
<td>3.2.1</td>
<td>Thermal comfort investigations in summer and hot climate countries</td>
</tr>
<tr>
<td>3.2.2</td>
<td>Cooling strategies</td>
</tr>
<tr>
<td>3.2.3</td>
<td>Climate chamber experiments</td>
</tr>
<tr>
<td>3.3</td>
<td>Visual comfort</td>
</tr>
<tr>
<td>3.3.1</td>
<td>Visual comfort from daylighting through side-lit windows</td>
</tr>
<tr>
<td>3.3.2</td>
<td>Other effects of daylighting</td>
</tr>
<tr>
<td>3.4</td>
<td>Acoustics comfort based on indoor environmental noise condition</td>
</tr>
<tr>
<td>3.5</td>
<td>Investigations of integrating indoor comfort factors</td>
</tr>
<tr>
<td>Summary of Chapter</td>
<td>3-26</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.0</td>
<td>RESEARCH METHODOLOGY</td>
<td></td>
</tr>
<tr>
<td>4.1</td>
<td>Introduction</td>
<td>4-1</td>
</tr>
<tr>
<td>4.2</td>
<td>Conceptual framework of the research</td>
<td>4-1</td>
</tr>
<tr>
<td>4.3</td>
<td>Preliminary work</td>
<td>4-9</td>
</tr>
<tr>
<td>4.4</td>
<td>Instruments: sensors used</td>
<td>4-10</td>
</tr>
<tr>
<td>4.4.1</td>
<td>Objective measurement procedures</td>
<td>4-12</td>
</tr>
<tr>
<td></td>
<td>4.4.1.1 Determining weather type (i.e.: either Rainy or Clear Days)</td>
<td>4-12</td>
</tr>
<tr>
<td></td>
<td>4.4.1.2 Indoor thermal objective measurement procedures</td>
<td>4-13</td>
</tr>
<tr>
<td></td>
<td>4.4.1.3 Daylighting measurement procedure</td>
<td>4-15</td>
</tr>
<tr>
<td></td>
<td>4.4.1.4 Sound pressure level measurement procedure</td>
<td>4-17</td>
</tr>
<tr>
<td>4.5</td>
<td>Subjective Measurement of Occupants’ Indoor Comfort Perceptions</td>
<td>4-18</td>
</tr>
</tbody>
</table>
4.5.1 **Instrument: Questionnaire survey** 4-19
4.5.2 **Subjective measurement procedure** 4-20
4.6 **Overall Indoor Comfort Perception Assessments** 4-25
4.7 **Statistical Analyses** 4-25
4.7.1 **Data processing and archival** 4-25
4.8 **Case study buildings descriptions** 4-28
4.8.1 **Geographical and climatic descriptions of case study sites** 4-28
4.8.2 **Selected Hostels** 4-36
    4.8.2.1 **Twelfth Residential College, Universiti Malaya (H1)** 4-36
    4.8.2.2 **Eleventh Residential College, Universiti Putra Malaysia (H2)** 4-40
    4.8.2.3 **Mumi Student Apartment, Universiti Tenaga Nasional (H3)** 4-45
4.8.3 **Measured rooms specifications and location of instruments** 4-49
**Summary** 4-62

### 5.0 OPERATIVE TEMPERATURE AND THERMAL COMFORT ASSESSMENTS

5.1 **Introduction** 5-1
5.2 **Results: Objective thermal measurements** 5-1
5.2.1 **Outdoor microclimate** 5-1
5.2.2 **Operative temperature measurements: without ceiling fan** 5-6
5.2.3 **Indoor temperatures measurements: with ceiling fan** 5-13
5.2.4 **Discussions and Findings: Operative Temperature Assessments** 5-28
5.3 **Results: Subjective thermal measurements** 5-32
5.3.1 **Subjective measurement details** 5-32
5.3.2 **Thermal comfort: rainy and clear days** 5-35
5.3.3 **Thermal comfort: daytime period** 5-40
5.3.4 **Thermal comfort: the influence of window** 5-41
5.3.5 **Results: Optimum thermal comfort and regression models** 5-42
5.3.6 **Discussions and Findings: Thermal Comfort Assessments** 5-45
**Summary** 5-46

### 6.0 DAYLIGHT RATIO, LUMINANCE OF WINDOW AND VISUAL COMFORT ASSESSMENTS

6.1 **Introduction** 6-1
6.2 **Results: Objective visual measurements** 6-1
6.2.1 **External and internal horizontal illumination** 6-1
9.0 CONCLUSIONS AND RECOMMENDATIONS

9.1 Introduction 9-1

9.2 Summary of the thesis problem 9-1

9.3 Conclusions based on thesis aim and objectives 9-2

9.4 Guidelines for improving occupants indoor comfort conditions in typical multi-storey hostels in Malaysia 9-7

9.5 Suggestions for future investigations 9-8

References

Appendices
List of Tables

<table>
<thead>
<tr>
<th>Chapter</th>
<th>No.</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2.1</td>
<td>Thermal sensation scales</td>
<td>2-6</td>
</tr>
<tr>
<td></td>
<td>2.2</td>
<td>Relationship between types of skies and the cloud cover justification.</td>
<td>2-13</td>
</tr>
<tr>
<td>3</td>
<td>3.1</td>
<td>Summary of thermal comfort experiments between observed and predicted</td>
<td>3-3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>neutralities in relation to outdoor climate in naturally ventilated buildings.</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>4.1</td>
<td>Activity types listed in questionnaire.</td>
<td>4-20</td>
</tr>
<tr>
<td></td>
<td>4.2</td>
<td>Daily wear clothing</td>
<td>4-21</td>
</tr>
<tr>
<td></td>
<td>4.3</td>
<td>Description of questions in Section B</td>
<td>4-21</td>
</tr>
<tr>
<td></td>
<td>4.4</td>
<td>Description of questions in Section C</td>
<td>4-22</td>
</tr>
<tr>
<td></td>
<td>4.5</td>
<td>Description of questions in Section D</td>
<td>4-23</td>
</tr>
<tr>
<td></td>
<td>4.6</td>
<td>Description of questions in Section E</td>
<td>4-24</td>
</tr>
<tr>
<td></td>
<td>4.7</td>
<td>Description of questions in Section F</td>
<td>4-24</td>
</tr>
<tr>
<td></td>
<td>4.8</td>
<td>Classification of effect size</td>
<td>4-27</td>
</tr>
<tr>
<td></td>
<td>4.9</td>
<td>Summary of Case Study Inventory</td>
<td>4-58</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gantt Chart 1</td>
<td>4-59</td>
</tr>
<tr>
<td>5</td>
<td>5.1</td>
<td>List of Rainy and Clear days during objective measurement period</td>
<td>5-5</td>
</tr>
<tr>
<td></td>
<td>5.2</td>
<td>Dry bulb temperature and relative humidity mean differences during rainy and clear days using ANOVA repeated measures</td>
<td>5-5</td>
</tr>
<tr>
<td></td>
<td>5.3</td>
<td>Statistical summary of dry bulb temperature, relative humidity and wind speed during measurement period (no fan)</td>
<td>5-6</td>
</tr>
<tr>
<td></td>
<td>5.4</td>
<td>Statistical summary of operative temperature for each hostel (no fan).</td>
<td>5-8</td>
</tr>
<tr>
<td></td>
<td>5.5</td>
<td>ANOVA repeated measures of operative temperature during rainy and clear day in H1, H2 and H3</td>
<td>5-12</td>
</tr>
<tr>
<td></td>
<td>5.6</td>
<td>Summary of mean estimation for operative temperature in the morning (8:00 am to 11:59 am), afternoon (12:00 pm to 2:59 pm) and evening (3:00 pm to 5:59pm) in H1, H2 &amp; H3</td>
<td>5-13</td>
</tr>
<tr>
<td></td>
<td>5.7</td>
<td>Statistical summary of dry bulb temperature, relative humidity and wind speed during measurement period (with fan)</td>
<td>5-14</td>
</tr>
<tr>
<td></td>
<td>5.8</td>
<td>Statistical summary of operative temperature for each hostel (with fan)</td>
<td>5-16</td>
</tr>
<tr>
<td></td>
<td>5.9</td>
<td>Statistical summary of air speed for each hostel with and without fan usage.</td>
<td>5-17</td>
</tr>
<tr>
<td>Section</td>
<td>Description</td>
<td>Page</td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>--------------------------------------------------------------------------------------------------</td>
<td>------</td>
<td></td>
</tr>
<tr>
<td>5.10</td>
<td>Statistical summary test using ANOVA repeated measures between operative temperature with and without fan usage for H1, H2 and H3</td>
<td>5-28</td>
<td></td>
</tr>
<tr>
<td>5.11</td>
<td>Summary of questionnaire survey detail</td>
<td>5-31</td>
<td></td>
</tr>
<tr>
<td>5.12</td>
<td>Summary of Subjects’ Personal Detail (Answers to questions in Section A)</td>
<td>5-33</td>
<td></td>
</tr>
<tr>
<td>5.13</td>
<td>Daily wear clothing</td>
<td>5-34</td>
<td></td>
</tr>
<tr>
<td>5.14</td>
<td>ANOVA repeated measures on daily wear clothing during Clear Days and Rainy Days collected from the three hostels</td>
<td>5-34</td>
<td></td>
</tr>
<tr>
<td>5.15</td>
<td>Summary of mean estimation for occupants’ thermal comfort during rainy &amp; clear day in H1, H2 &amp; H3 using ANOVA repeated measures. Cold (-3) to Hot (3)</td>
<td>5-35</td>
<td></td>
</tr>
<tr>
<td>5.16</td>
<td>Summary of mean estimation for occupants’ thermal comfort in the morning, afternoon and evening in H1, H2 &amp; H3 using ANOVA repeated measures. Cold (-3) to Hot (3)</td>
<td>5-40</td>
<td></td>
</tr>
<tr>
<td>6.1</td>
<td>Summary of external horizontal illumination during measurement period</td>
<td>6-2</td>
<td></td>
</tr>
<tr>
<td>6.2</td>
<td>ANOVA repeated measures of External illumination during rainy and clear day in H1, H2 and H3</td>
<td>6-2</td>
<td></td>
</tr>
<tr>
<td>6.3</td>
<td>Internal horizontal illumination level in measured rooms on the first, fifth and top floors of H1, H2 and H3</td>
<td>6-4</td>
<td></td>
</tr>
<tr>
<td>6.4</td>
<td>Daylight ratio (%) level in measured rooms on the first, fifth and top floors of H1, H2 and H3</td>
<td>6-6</td>
<td></td>
</tr>
<tr>
<td>6.5</td>
<td>ANOVA repeated measures of daylight ratio during Rainy and Clear Days in H1, H2 and H3</td>
<td>6-9</td>
<td></td>
</tr>
<tr>
<td>6.6</td>
<td>ANOVA repeated measures of daylight ratio in the morning (8:00 am to 11:59 am), afternoon (12:00 pm to 2:59 pm) and evening (3:00 pm to 5:59pm) in H1, H2 &amp; H3</td>
<td>6-10</td>
<td></td>
</tr>
<tr>
<td>6.7</td>
<td>Luminance of window (cd/m2) level in measured rooms on the first, fifth and top floors of H1, H2 and H3</td>
<td>6-11</td>
<td></td>
</tr>
<tr>
<td>6.8</td>
<td>ANOVA repeated measures of luminance of window during Rainy and Clear Days in H1, H2 and H3</td>
<td>6-13</td>
<td></td>
</tr>
<tr>
<td>6.9</td>
<td>ANOVA repeated measures of luminance of window in the morning (8:00 am to 11:59 am), afternoon (12:00 pm to 2:59 pm) and evening (3:00 pm to 5:59pm) in H1, H2 &amp; H3</td>
<td>6-14</td>
<td></td>
</tr>
<tr>
<td>6.10</td>
<td>Summary of mean estimation for occupants’ visual comfort during rainy &amp; clear day in H1, H2 &amp; H3 using ANOVA repeated measures. Dark (-3) to Bright (3)</td>
<td>6-16</td>
<td></td>
</tr>
<tr>
<td>6.11</td>
<td>Summary of mean estimation for occupants’ visual comfort in the morning, afternoon and evening in H1, H2 &amp; H3. Dark (-3) to Bright (3)</td>
<td>6-19</td>
<td></td>
</tr>
<tr>
<td>6.12</td>
<td>Correlation between occupant’s curtain usage with glare during clear day</td>
<td>6-23</td>
<td></td>
</tr>
</tbody>
</table>
6.13 Correlation between occupant’s artificial lighting usage with daylight availability during clear day

7.1 Mean wind direction during measurement periods
7.2 Indoor noise level in measured rooms on the first, fifth and top floors of H1, H2 and H3
7.3 ANOVA repeated measures of noise equivalent in one hour, $L_{eq(1)}$, during rainy and clear day in H1, H2 and H3
7.4 ANOVA repeated measures of noise equivalent in one hour, $L_{eq(1)}$, in the morning (8:00 am to 11:59 am), afternoon (12:00 pm to 2:59 pm) and evening (3:00 pm to 5:59 pm) in H1, H2 & H3
7.5 Summary of mean estimation for occupants’ acoustics comfort during Rainy & Clear Day in H1, H2 & H3 using ANOVA repeated measures. Noisy (-3) to Quiet (3)
7.6 Summary of mean estimation for occupants’ acoustics comfort in the morning, afternoon and evening in H1, H2 & H3 using ANOVA repeated measures. Noisy (-3) to Quiet (3)
7.7 Summary of mean estimation for occupants’ acoustic comfort when the window is opened and closed in H1, H2 and H3 using ANOVA repeated measures. Never (-3) to Always (3)
7.8 Summary of vote whether external noise annoys occupants or not using ANOVA repeated measures. Annoyed (-3) to Not Annoyed (3)

8.1 Summary of vote for overall indoor comfort satisfaction using ANOVA repeated measures. Dissatisfied (-3) to Satisfied (3)
8.2 Relationship between overall indoor comfort satisfaction (DV) and architectural features (IV) using multiple linear regression
8.3 Relationship between overall indoor comfort satisfaction (DV) and Individual indoor comfort perceptions (IV) using multiple linear regression
8.4 Friedman Test means ranks from H1, H2 and H3 occupants
## List of Figures

<table>
<thead>
<tr>
<th>Chapter</th>
<th>No.</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.1</td>
<td>The research flow</td>
<td>1-11</td>
</tr>
<tr>
<td>2</td>
<td>2.1</td>
<td>The ‘core’ (shaded) and shell of the body</td>
<td>2-3</td>
</tr>
<tr>
<td></td>
<td>2.2</td>
<td>Solar noon sun angles for the equator</td>
<td>2-12</td>
</tr>
<tr>
<td></td>
<td>2.3</td>
<td>(a) Clear sky vault and (b) Clear sky condition</td>
<td>2-14</td>
</tr>
<tr>
<td></td>
<td>2.4</td>
<td>(a) Overcast sky vault and (b) Overcast sky condition</td>
<td>2-15</td>
</tr>
<tr>
<td></td>
<td>2.5</td>
<td>Daylight availability in Subang, Malaysia</td>
<td>2-16</td>
</tr>
<tr>
<td></td>
<td>2.6</td>
<td>Decibel scale for sounds</td>
<td>2-18</td>
</tr>
<tr>
<td></td>
<td>2.7</td>
<td>The effect of temperature variations on sound propagation direction. The shaded area is the shadow zone</td>
<td>2-22</td>
</tr>
<tr>
<td></td>
<td>2.8</td>
<td>The effects of wind currents on sound propagation direction. The shaded area is the shadow zone</td>
<td>2-22</td>
</tr>
<tr>
<td></td>
<td>2.9</td>
<td>Kuala Lumpur’s Sun Path</td>
<td>2-23</td>
</tr>
<tr>
<td></td>
<td>2.10</td>
<td>Surface reflectance opposite a window wall</td>
<td>2-24</td>
</tr>
<tr>
<td></td>
<td>2.11</td>
<td>Direct and diffuse solar radiation transmittance through glass</td>
<td>2-25</td>
</tr>
<tr>
<td></td>
<td>2.12</td>
<td>Characteristics of sidelighting, toplighting and atria</td>
<td>2-26</td>
</tr>
<tr>
<td></td>
<td>2.13</td>
<td>Illumination gradient showing at section view based on three opening locations</td>
<td>2-27</td>
</tr>
<tr>
<td></td>
<td>2.14</td>
<td>Simple feedback scheme</td>
<td>2-31</td>
</tr>
<tr>
<td>4</td>
<td>4.1</td>
<td>Schematic depiction of fluxes involved in the indoor comfort of a single storey building</td>
<td>4-2</td>
</tr>
<tr>
<td></td>
<td>4.2</td>
<td>Comparison of good and bad hostel building envelope designs with heat, daylight and sound from their immediate surrounding</td>
<td>4-4</td>
</tr>
<tr>
<td></td>
<td>4.3</td>
<td>Hierarchy of influences on physical indoor factors in typical hostels in Malaysia</td>
<td>4-6</td>
</tr>
<tr>
<td></td>
<td>4.4</td>
<td>Hierarchy of influences on occupants’ indoor comfort in typical hostels in Malaysia</td>
<td>4-7</td>
</tr>
<tr>
<td></td>
<td>4.5</td>
<td>Interaction of predominant indoor comfort factors with objective, subjective, architectural and daytime period influences in creating comfortable indoor condition in typical multi-storey hostels in Malaysia</td>
<td>4-8</td>
</tr>
<tr>
<td></td>
<td>4.6</td>
<td>Schematic diagram of horizontal 40 ° view band</td>
<td>4-17</td>
</tr>
<tr>
<td></td>
<td>4.7</td>
<td>Map of Western and Eastern Malaysia</td>
<td>4-30</td>
</tr>
<tr>
<td></td>
<td>4.8</td>
<td>Monthly maximum, minimum and average temperatures in Petaling Jaya (1971-2006)</td>
<td>4-31</td>
</tr>
<tr>
<td></td>
<td>4.9</td>
<td>Monthly maximum and average rainfall and relative humidity in Petaling Jaya (1971-2006)</td>
<td>4-31</td>
</tr>
</tbody>
</table>
4.10 Monthly maximum, minimum and average temperatures in KLIA (1998-2006)

4.11 Monthly maximum and average rainfall and relative humidity in KLIA (1998-2006)

4.12 Klang Valley map

4.13 Universiti Malaya campus map (not to scale)

4.14 Typical floor layout for H1

4.15 Universiti Putra Malaysia (UPM) campus map

4.16 Typical floor plan layout for H2

4.17 Universiti Tenaga Nasional campus map

4.18 Typical floor plan layout for H3

4.19 Dimension of H1 room and locations of sensors: ‘A’, ‘B’ and ‘C’

4.20 View A in H1 room

4.21 Section X – X’ of H1 room

4.22 Dimension of H2 room and locations of sensors: ‘A’, ‘B’ and ‘C’

4.23 View A in H2 room

4.24 Section X - X’ of H2 room


4.26 View A in H3 room

4.27 Section X - X’ of H3 room

4.28 Research procedure flow

5.1 Daily maximum, minimum & average in H1 for: (a) Temperature; (b) Relative Humidity; & (c) Wind Speed

5.2 Daily maximum, minimum & average in H2 for: (a) Temperature; (b) Relative Humidity; & (c) Wind Speed

5.3 Daily maximum, minimum & average in H3 for: (a) Temperature; (b) Relative Humidity; & (c) Wind Speed

5.4 Mean Operative Temperature without fan at different vertical room locations in H1, H2 and H3

5.5 Mean Operative Temperature without fan at different room orientation in: (a) H1; (b) H2 and (c) H3

5.6 Mean operative temperature with fan at different vertical room locations in H1, H2 and H3

5.7 Mean Operative Temperature with fan at different room orientation in: (a) H1; (b) H2 and (c) H3.

5.8 Operative temp. (To) swing in H1 North without fan (12-14/05/07) & with fan (15-17/05/07)

5.9 Operative temp. (To) swing in H1 South without fan (19-21/05/07) & with fan (24-26/05/07)
5.10 Operative temp. (To) swing in H2 South-east without fan (27-30/05/07) & with fan (31-02/06/07)

5.11 Operative temp. (To) swing in H2 South-west without fan (02-05/06/07) & with fan (06-08/06/07)

5.12 Operative temp. (To) swing in H2 North-east without fan (09-12/06/07) & with fan (13-15/06/07)

5.13 Operative temp. (To) swing in H2 North-west without fan (17-19/06/07) & with fan (20-22/06/07)

5.14 Operative temp. (To) swing in H3 West without fan (23-26/06/07) & with fan (27-29/06/07)

5.15 Operative temp. (To) swing in H3 North without fan (30/06-03/07/07) & with fan (04-06/07/07)

5.16 H1 sample distribution against different level

5.17 H2 sample distribution against different level

5.18 H3 sample distribution against different level

5.19 Occupants’ perception on their room’s humidity level during Rainy Day: (a), (c) & (e); Clear Day: (b), (d) & (f). Dry (-3) to Humid (3)

5.20 Occupants’ perception on their room’s airflow level during Rainy Day: (a), (c) & (e); Clear Day: (b), (d) & (f). Draughty (-3) to Stuffy (3)

5.21 Thermal comfort when the window is opened in (a) rainy day; & (b) clear day. Cold (-3) to Hot (3)

5.22 Occupants’ votes on: (a) room draughtiness and (b) room humidity when windows are opened. Never (-3) to Always (3)

5.23 Regression of occupants’ thermal comfort vote for rainy and clear days against operative temperature in: (a) H1; (b) H2 and (c) H3.

6.1 Mean Daylight Ratio at different vertical room locations in H1, H2 and H3

6.2 Mean Daylight Ratio at different room orientation in: (a) H1; (b) H2 and (c) H3

6.3 Mean Luminance of window at different vertical room locations in H1, H2 and H3

6.4 Mean Luminance of window at different room orientation in: (a) H1; (b) H2 and (c) H3

6.5 Enough daylighting in Rainy Day: (a), (c) & (e); Clear day: (b), (d) & (f). Inadequate (-3) to Adequate (3)

6.6 Satisfy with daylighting performance in room for: (a) H1; (b) H2 & (c) H3. Dissatisfied (-3) to Satisfied (3)

6.7 Window allows adequate daylighting into your room for: (a) H1; (b) H2 & (c) H3. Disagree (-3) to Agree (3)

6.8 Do you pull the curtain on a Clear Day? (a) H1; (b) H2 & (c). H3 Never
Do you switched on the lights on Clear Day? (a) H1; (b) H2 & (c) H3.

Never (-3) to Always (3)

7

7.1 Noise equivalent in one hour at different vertical room locations in H1, H2 and H3
7.2 Noise equivalent in one hour at different room orientation in: (a) H1; (b) H2 and (c) H3
7.3 Occupants' reaction toward traffic noise received in their room when: (a) window is opened; and (b) window is closed. Never (3) to Always (-3)

List of Plates

<table>
<thead>
<tr>
<th>Chapter</th>
<th>No.</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>4.1</td>
<td>ELTEK data logger</td>
<td>4-11</td>
</tr>
<tr>
<td></td>
<td>4.2</td>
<td>Relative humidity &amp; air temperature probe</td>
<td>4-11</td>
</tr>
<tr>
<td></td>
<td>4.3</td>
<td>Ping pong globe thermometer</td>
<td>4-11</td>
</tr>
<tr>
<td></td>
<td>4.4</td>
<td>AIRFLOW thermo-anemometer</td>
<td>4-11</td>
</tr>
<tr>
<td></td>
<td>4.5</td>
<td>ISO-TECH lux meter</td>
<td>4-11</td>
</tr>
<tr>
<td></td>
<td>4.6</td>
<td>HAGNER photometer</td>
<td>4-11</td>
</tr>
<tr>
<td></td>
<td>4.7</td>
<td>Nikon CoolPix 990 with fish eye lens</td>
<td>4-11</td>
</tr>
<tr>
<td></td>
<td>4.8</td>
<td>DAWE D-1422C digital impulse sound pressure level</td>
<td>4-11</td>
</tr>
<tr>
<td></td>
<td>4.9</td>
<td>Sound meter, globe, air and RH sensors</td>
<td>4-15</td>
</tr>
<tr>
<td></td>
<td>4.10</td>
<td>Air speed measurement</td>
<td>4-15</td>
</tr>
<tr>
<td></td>
<td>4.11</td>
<td>Recording external illumination in a field near by to a selected hostel</td>
<td>4-17</td>
</tr>
<tr>
<td></td>
<td>4.12</td>
<td>Boxed location shows near-by high-way viewed from North facing measured room on 9th floor of H1</td>
<td>4-39</td>
</tr>
<tr>
<td></td>
<td>4.13</td>
<td>Elevation of H1</td>
<td>4-39</td>
</tr>
<tr>
<td></td>
<td>4.14</td>
<td>Typical view of a room in H1</td>
<td>4-40</td>
</tr>
<tr>
<td></td>
<td>4.15</td>
<td>Boxed location shows near-by high-way viewed from North-west facing measured room on 7th floor of H2</td>
<td>4-43</td>
</tr>
<tr>
<td></td>
<td>4.16</td>
<td>Elevation of H2</td>
<td>4-44</td>
</tr>
<tr>
<td></td>
<td>4.17</td>
<td>Typical view of a room in H2</td>
<td>4-44</td>
</tr>
<tr>
<td></td>
<td>4.18</td>
<td>View of near-by high-way viewed from North facing measured room on 10th floor of H3</td>
<td>4-47</td>
</tr>
<tr>
<td></td>
<td>4.19</td>
<td>Elevations of H3: View A and View B</td>
<td>4-48</td>
</tr>
<tr>
<td></td>
<td>4.20</td>
<td>Typical view of a room in H3</td>
<td>4-48</td>
</tr>
<tr>
<td></td>
<td>4.21</td>
<td>(a) Close up of elevation of H1 and (b) louver window</td>
<td>4-51</td>
</tr>
<tr>
<td></td>
<td>4.22</td>
<td>(a) Close up of elevation of H2 and (b) top hung windows</td>
<td>4-54</td>
</tr>
<tr>
<td></td>
<td>4.23</td>
<td>(a) Close up of elevation of H3 and (b) side hung windows</td>
<td>4-57</td>
</tr>
</tbody>
</table>
CHAPTER 1

INTRODUCTION

1.1 Background

Malaysia is now experiencing a growth in the number of individuals attending colleges. Utusan (2009) reports, “Higher education enrolment in Malaysia is expected to provide for 260,000 places in more than 600 colleges in the year 2009”. This scenario leads to the booming of multi-storey hostels in college campuses. However, there has been little change in room layout since the 60s. Students stayed in shared accommodation with at most 4 students at one time. The hostel rooms are not en-suite and rarely designed with projected balconies. Rooms are also not air-conditioned but are compensated with ceiling fans.

Why do we need to assess the indoor comfort perceptions of student occupants staying in non-air-conditioned hostels? In an earlier survey conducted by Dahlan et al. (2008) observed that students living in non-air-conditioned university hostels in Malaysia were most likely to feel thermally uncomfortable in rooms without projected balconies through their thermal comfort predicted mean vote (PMV) investigations. An investigation on perception of indoor environmental quality of occupants in high-rise residential buildings in Hong Kong found that thermal comfort was perceived as the most important indoor environmental quality attribute to its occupants. This was followed by air cleanliness, odour and finally noise (Lai 2009). However, the subjects for this particular investigation were not students and the level of occupant freedom
was not constrained by strict building management rules such as practiced in public university student hostels. Unlike private dwellers, students staying in hostels are prohibited to install air conditioning system and other high voltage electrical appliances in order to compensate for their indoor comfort. Previous studies on student accommodations have focused only on the physical performance of the building (Kruger 2008) or occupants' perceptions on its design, such as, the building layout; floor heights and room views (Kaya 2001; Abu-Obeid 2002; Devlin 2008).

According to the World Health Organisation, the health of the occupants and their satisfaction on their homes can be affected by multifaceted environmental performance of a building, in respect of the quality of indoor thermal, visual and acoustic environments and indoor air quality (WHO 1990). Other indoor environmental terms that can be related to occupants' comfort perception have been stated by the Chartered Institution of Building Services Engineers (CIBSE) (CIBSE 2006a), namely: indoor air temperature; air flow; relative humidity; mean radiant temperature; illumination; discomfort glare; noise annoyance; indoor air quality; vibration; electromagnetic and electrostatic environment. However, not all physical environments are equally important to the occupants. Researchers usually analysed either the top eight or adding other distinguish type of comfort into their system to suit contextual comfort needs (Gonzalez 1997; Chiang 2001; Chiang and Lai 2002; Kim 2005; Mahdavi and Unzeitig 2005; Chau 2006). The decision to analyse occupants' perceptions toward thermal, visual and acoustic indoor conditions was based on the fact that occupants in Malaysia were familiar with the thermal, visual and acoustic environments. Non-air-conditioned residential buildings that are not climate-controlled are rarely exposed to machinery vibration, chemical and microbial
problems. Moreover, no complaints on electromagnetic and electrostatic problems from occupants in residential areas in Malaysia were documented so far.

In identifying which indoor environment influenced occupants’ overall indoor comfort perception, researchers resolve to prioritise the individual indoor comfort perceptions. Why is prioritising indoor environment important? Through this method, problematic indoor environment issues that reduce occupants’ indoor comfort perception can be tackled. Once the problem is identified, architects can focus on new ways to improve their designs in the future or even conduct a small alteration to rectify the particular problem. It is also a useful tool to assess the building performance’s effects on its occupants.

Little is known on how residential occupants in Malaysia living in non-air-conditioned residential building such as hostels rank their indoor environments. This study provides the opportunity to compare the relative importance of physical indoor conditions, which include thermal, visual and acoustic conditions, with the student occupants’ indoor comfort perceptions in typical Malaysian multi-storey hostels. Data from operative temperature, daylight ratio and sound pressure levels are measured, which provides the ambient indoor condition surrounding the student occupant. The indoor conditions are then prioritised in order to determine their influence on the student occupants when staying in their hostel rooms. To achieve this aim, the following objectives were derived:

i. To review the literatures on indoor condition assessments related to occupants’ comfort in multi-storey buildings in Malaysia.
ii. To propose a conceptual framework of integrated indoor comfort factors that illustrates the Architectural Systems in which multi-storey hostels in Malaysia functions.

iii. To assess indoor thermal, visual and noise conditions in multi-storey hostels by means of objective measurements.

iv. To assess occupants’ indoor thermal, visual and noise comfort perceptions in multi-storey hostels by means of questionnaire survey.

v. To identify the overall indoor comfort satisfaction of occupants living in multi-storey hostels in Malaysia.

vi. To propose guidelines in improving occupants’ indoor comfort conditions in typical multi-storey hostels in Malaysia.

1.2 Case study buildings characteristics

Case study hostels had similar characteristics as mentioned below:

i. **Height of the building:** The highest hostels in university campuses were selected. Selected hostels were above 5 storeys high.

ii. **Non-air-conditioned:** Hostels were non-air-conditioned and only have a ceiling fan installed per-room.
iii. **Minimal level of activity:** Most of the times, occupants were doing sedentary activities or less; such as studying, socialising and resting or sleeping.

iv. **Female accommodation:** In this investigations, the hostel with separate student accommodation (i.e.: female only accommodation) were chosen. This criterion was considered important because in Malaysia, Muslim female students are taught to avoid visual contact from the male. By providing a separate accommodation, female students are more relax in their curtain usage, thus it can be assumed that they do not pull their curtain all the time which deprived daylighting into their rooms.

v. **Controlled respondents:** Respondents should be restricted to occupants living in these hostels, namely, college aged female – local - university students.

Different characteristics of the hostels were limited to the following six characteristics:

i. **Window designs and dimensions:** Variety window design could be useful in comparing the effects on thermal, daylight and noise available indoors.

ii. **Projected balcony adjacent to the window wall of measured rooms:** At least one of the selected hostels should have projected balcony located adjacent to its window wall. The reason for this characteristic
is so that the author can examine the effects of this particular design feature on its adjacent indoor condition.

iii. **Floor levels:** Measured rooms were chosen at three different floor levels, namely at the lower, middle and top floor level.

iv. **Room orientations:** Measured rooms were selected based on their orientations in order to investigate the outdoor microclimate effects on the indoor comfort.

v. **Ceiling fan functions:** Thermal assessments were conducted when the ceiling fans in the measured rooms were switched on and off. The importance of this assessment is to identify how much air speed is needed to increase occupants' thermal comfort.

vi. **Distance from a highway:** Hostels built near high-ways were selected in this study (i.e.: estimated below 100m distance between the nearest hostel block and the highway). The effects of traffic noise to occupants should be useful in identifying their level of indoor acoustic comfort.

**1.3 Scope and limitation of research**

This research was focused on the effects of indoor environment through operative temperature, daylight and environmental noise in multi-storey hostels in Malaysia. From the effects of the mentioned indoor environment in this particular building, investigations on the occupants' indoor thermal, visual and acoustic comfort perceptions were conducted. Subsequently, integration of effects from the three indoor comfort factors was also investigated.
Samples were collected among college-aged students available in the measured hostels. However due to hostel regulations, the author was allowed to collect samples from female students only. Students were chosen because their indoor comfort perceptions were not mainly influenced by economical reasons unlike other dwellers such as occupants in flats or apartments because the students were given sponsorships. Moreover, hostel regulations do not allow the students to install air conditioning systems; therefore their acclimatisation option was restricted to only ceiling fan usage.

Due to the strict time limitation and complex nature of the parameters mentioned, analyses were conducted on relative measurement basis. Limitations are listed according to individual investigations as follows:

1. Thermal investigations consisted of air temperature, relative humidity, mean radiant temperature and air speed measurement. Thermal conditions were measured with and without ceiling fan usage. Windows in measured rooms were left open throughout the measurement period. This investigation does not include thermal condition at the balcony area.

2. Visual investigations consist of daylight ratio and luminance of window restricted to transmittance through side-lit windows and the effects of conventional shading strategies i.e.: roof overhang, and balcony. This particular investigation does not include measurement of reflected daylight component from near by buildings or other structure.
3. Acoustics investigations restricted to external noise transmitted through open window. Noise from within the interior spaces of the hostels, i.e.: from next room or corridor was not considered.

1.4 Hypotheses and Research Questions

In accordance to the background of this study, the following hypotheses were instigated:

i. Multi-storey building’s physical indoor conditions vary as its floor level increases.

ii. Occupants living in multi-storey buildings in Malaysia are tolerant with the physical thermal, visual and acoustics conditions in their rooms.

iii. Integration of more than one physical indoor condition provides closer resemblance to occupants’ overall indoor comfort perception.

In the light to understand the hypotheses provided, this study was prompted to answer the following research questions:

i. How does the outside condition of a multi-storey building differ in terms of operative temperature, daylighting, and noise level in each measured room?
ii. How would occupants living in multi-storey building react to their indoor thermal, visual and acoustics conditions?

iii. Does collective works on indoor comfort factors (i.e.: thermal, visual and acoustics) lead to better understanding of occupants indoor comfort perceptions?

1.5 Research flow

To give a clear understanding of the study, a research flow is illustrated in Figure 1.1. The research flow consists of three phases. In the first phase, the author build up the preliminary stages of the research, namely, through literature reviews, developing the conceptual framework and testing the research methodology. The former two stages discussed the theoretical understanding in reference to the research scope. Subsequently, the assumptions gathered formed the basis of step by step investigation procedures that were later tested through series of pilot tests. Revised investigation procedures were used in the field works in Malaysia. Explanations regarding the mentioned stages are provided in Chapters 2 to 4.

In the second phase, field works (i.e.: objective and subjective) were done in hostels that were typical in Malaysia and focused on three parameters, namely, thermal, visual and acoustics conditions. Descriptions of the selected case study hostels were gathered prior to the field works. Outdoor and indoor measurements (objective) for the three conditions were conducted prior to the questionnaire surveys (subjective). Results from thermal, visual and acoustics assessments were discussed in
individual chapters in order to provide in depth explanations of each parameter, namely, in Chapters 5, 6 and 7, respectively.

In the third phase, the author assessed the occupants’ indoor comfort perceptions through the combination of the three parameters mentioned. Results and discussions of their perceptions were crossed examined with selected architecture features, weather and daytime conditions during the field works, which were explained in Chapter 8. In the light to exhibit the importance of the occupants’ indoor comfort perception in evaluating a hostel’s indoor environment, findings from Chapters 5, 6 and 7 were constantly referred in this chapter. This final phase was closed with Chapter 9.

Summary

This chapter highlights the need to have acceptable indoor climate condition to ensure satisfactory occupant comfort in Malaysian typical dwelling design. Focus was given to multi-storey university hostels in the Klang Valley. To further understand the current scenario related to this research, literatures supporting the research scope were reviewed in Chapters 2 and 3.
PHASE 1

Chapters 2 & 3

Chapter 4

Preliminary Research Procedures

Invalid

valid

Revised Research Procedures

PHASE 2

Chapters 5, 6 & 7

Case studies assess using the following parameters:

- THERMAL
  - Outdoor Objective
  - Indoor Objective
  - Occupants Subjective

- VISUAL
  - Outdoor Objective
  - Indoor Objective
  - Occupants Subjective

- ACOUSTICS
  - Outdoor Objective
  - Indoor Objective
  - Occupants Subjective

Occupants' reaction towards combined indoor environment factors

Proposed design features

PHASE 3

Chapters 8 & 9

Figure 1.1: The research flow
CHAPTER 2

REVIEW OF FUNDAMENTAL THEORIES ON INDOOR CLIMATE & COMFORT PERCEPTIONS

2.1 Introduction

This chapter provides reviews on fundamental theories related to indoor climate and comfort perceptions in buildings that have ceiling fan and naturally lit. Literatures reviewed are divided into three main sections, namely, (1) reviews of fundamental issues related to thermal, visual and acoustics comforts; (2) design features of naturally ventilated and lit buildings; and (3) understanding the influence of architectural features of a building to the occupants’ comfort perceptions.

2.2 Review of indoor comfort factors

This review discusses the models and theories that are available within the field of thermal, visual and acoustic comforts related to the research scope.

2.2.1 Thermal condition and comfort perception: models and theories

Thermal comfort is available where there is broad satisfaction with the thermal environment i.e. most people are neither too hot nor too cold. Another way to regard this is as an absence of discomfort (CIBSE 2006a; CIBSE 2006b). Key factors influencing thermal comfort are namely, temperature, humidity, air movement and air quality. If our environment is not thermally comfortable, we could experience anxiety or heat stress. This is explained using heat balance theory.
2.2.1.1 Heat Balance Theory

Heat balance theory is how one’s thermal comfort is influenced exclusively by the physics of the body’s thermal balance in order to adapt to its immediate environment. Human heat balance is achieved through mean skin temperature and sweat evaporation (De Dear 1994). The overall rate of all the chemical reactions in the human body is known by metabolic rate and usually expressed in terms of units of heat.

The rate of heat production for an average person, namely, the amount of heat produced when we sleep is around 60W. The more active we are the more heat is produced. For example when doing normal office work we generate around 140 W, with this increasing to around 250 W for physical activity such as dancing or gym work (CIBSE 2006b).

Human’s deep body temperature is maintained at about 37°C and most people in the west are comfortable within the environmental temperature of about 20 - 25°C in summer (Oke 1978). Deep body is referred to the core of the body where the vital organs are, namely, the brain, spinal cord, heart, liver, kidney, and etc. The overall heat content of the body can be altered depending on the outer shell’s depth (Figure 2.1). In other words, the outer shell acts as a buffer for the core from losing or gaining heat. This scenario describes the term ‘storage’ derived from the fundamental heat balance equation mentioned earlier (Endholm 1978). Oke added that if the subject is indoors with less air movement (less than 0.1m/s), the body metabolic heat production is dissipated to the environment through radiation (around 60%), convection of sensible heat (around 15%) and evaporation from the lungs and skin (around 25%).
In terms of skin albedo, dark (or black) skin absorbs short-wave radiation to a maximum depth of 0.4mm (i.e.: not piercing the epidermis), but in white skin, it reaches 2mm (i.e.: piercing the dermis). This means that heat absorbs by dark skin is contained near the surface of the skin where it can be easily lost, whereas in white skin heat is taken into the blood and contributes more to the general body heat storage problem (Oke 1978). To provide for greater peripheral thermal resistance, the clothing insulation is adjusted according to the environment. In the hot-humid climate, clothing worn is light weight and has minimum layering. The reason for these clothing characteristics is to allow sweating circulations (Oke 1978).

2.2.1.2 Measuring operative temperature

Assessment of indoor warmth for human comfort can be done through operative temperature. Operative temperature is used to describe radiant heat exchange that take place via convection and radiation, which includes three factors, namely, air temperature, radiant temperature and air movement. In this study, operative temperature is measured by means of globe thermometer consisting of a
hollow sphere (painted in black) that is exposed to the environment with a thermometer sensor bead at the centre. The internal temperature of the sphere indicates the balance between heats lost and gained from radiation and convection with reading range from -40°C to 60°C.

Various diameter globes have been experimented ranging from 150 and 38 mm. The earlier diameter globe gives an approximately correct direct reading of operative temperature for human subject; however, it is sometimes inconveniently large for practical use. Smaller diameter globe has larger convection coefficient than the larger globe at the same air speed. The 38mm ping pong ball was used as the sphere for the sensor because this particular diameter provides more convenient and quicker response compared to the 150mm globe, and it is preferable for assessing room warmth when the air movement is slight (i.e.: <0.2 m/s) (Humphreys 1977).

In other words, the operative temperature is numerically the average of the air temperature and mean radiant temperature, weighted by their respective heat transfer coefficients (ASHRAE 1992). For higher accuracy, the operative temperature was calculated using the formula:

\[
T_o = A \ T_a + (1 - A) \ T_{mrt}
\]  

(2.1)

where, \(T_o\) is operative temperature, °C; \(T_a\) is air temperature, °C; \(A\) is the airflow: 0.5 when air velocity is <0.2 m/s, 0.6 when air velocity between 0.2 and 0.6 m/s, and 0.7 when air velocity between 0.6 and 1.0 m/s; \(T_{mrt}\) is mean radiant temperature, °C.
2.2.1.3 Analytical thermal comfort models

The idea of thermal comfort was initiated from the west, where occupants demanded that the indoor air temperature be controlled. Studies in the twenties and thirties, both in the U.K and U.S.A. introduced the comfort zone concept, which suggested the thermal condition where majority of people would feel most comfortable (Fendholm 1978).

Fanger’s thermal comfort model using Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) indices are the most commonly adopted as both of them are included in the ISO 7730 (Fanger 1970). In this model, six factors are identify to influence human thermal sensation, namely, occupants’ clothing insulation value, their metabolic rate, air temperature, relative humidity, air speed and mean radiant temperature. It is based on experiments with American college-aged persons exposed to a uniform environment in climate chamber. The comfort equation establishes the relationship among the environment variables, clothing type and activity levels. It represents the heat balance of the human body in terms of the net heat exchange arising from the effects of the six factors identified. Finally with these variables Finger could establish the general comfort Equation (2.2):

\[
\begin{align*}
(M/A_{DB}) & \times (1-\eta) - 0.35 \left[ 43 - 0.0061 \left( M/A_{DB} \right) \times (1-\eta) - P \right] - 0.42 \left[ (M/A_{DB}) \times (1-\eta) - 50 \right] \\
- 0.0023 \left( M/A_{DB} \right) \times (44 - Pa) - 0.0014 \left( M/A_{DB} \right) \times (34 - Ta) \\
= 34 \times 10^{-8} \times f_{cl} \left[ \left( t_{cl} + 273 \right)^{4} - \left( t_{mrt} + 273 \right)^{4} \right] + f_{cl} \times h_{c} \times \left( t_{cl} - t_{a} \right) 
\end{align*}
\]

(2.2)

It is clear from Equation 2.2 that the human thermal comfort is a function of:

(i) The type of clothing surface temperature \( t_{cl} \), clothing surface area factor \( f_{cl} \)
(ii) The type of activity, effective mechanical power ($\eta$), and metabolic rate ($M/A_D$).

(iii) Environmental variables air velocity ($V$), air temperature ($t_a$), mean radiant temperature ($t_{\text{mrt}}$) and water vapour partial pressure ($P_a$) or relative humidity.

In order to assess the limit of the zone, questionnaires employed were measured using a seven point psycho-physical scale. Four other best known scales, namely, The American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE), Bedford, DISC and Preference Scales are also shown in Table 2.1.

Table 2.1: Thermal sensation scales

<table>
<thead>
<tr>
<th>Point</th>
<th>Fanger's scale</th>
<th>Point</th>
<th>ASHRAE scale</th>
<th>Bedford Scale</th>
<th>DISC Scale</th>
<th>Preference Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Hot</td>
<td>7</td>
<td>Hot</td>
<td>Much too warm</td>
<td>Very uncomfortable</td>
<td>Cooler</td>
</tr>
<tr>
<td>2</td>
<td>Warm</td>
<td>6</td>
<td>Warm</td>
<td>Too warm</td>
<td>Uncomfortable</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Slightly warm</td>
<td>5</td>
<td>Slightly warm</td>
<td>Comfortably warm</td>
<td>Slightly uncomfortable</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>Neutral</td>
<td>4</td>
<td>Neutral</td>
<td>Comfortable (neither warm not cool)</td>
<td>Comfortable</td>
<td>No Change</td>
</tr>
<tr>
<td>-1</td>
<td>Slightly cool</td>
<td>3</td>
<td>Slightly cool</td>
<td>Comfortably cool</td>
<td>-</td>
<td>Warmer</td>
</tr>
<tr>
<td>-2</td>
<td>Cool</td>
<td>2</td>
<td>Cool</td>
<td>Too cool</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>-3</td>
<td>Cold</td>
<td>1</td>
<td>Cold</td>
<td>Much too cool</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

Modified from de Dear, R (1994)

Occupants either within a free running or climate controlled building are considered comfortable if their indoor operative temperature is positively correlated with climate conditions prevailing outdoors. However, the exact range of indoor operative temperatures is not to be universally applied instead should be in correspond with the countries climate context and occupants’ clothing (De Dear 1994).
2.2.1.4 Adaptive Theory

Adaptive theory in thermal comfort is indicated through one’s satisfaction with an indoor climate, pertaining from the actual thermal environmental condition prevailing at that point in time and space, and one’s thermal expectations of what the indoor climate should be like (De Dear 1994). There are three classes of thermal comfort field measurement protocols for indoor climate measurement (Brager 1998). The Class I field measurement protocol required the measurement probes (i.e.: air temperature, relative humidity, mean radiant temperature, air speed probes) to be placed at 3 different vertical points located next to a sitting respondent. The Class II field measurement protocol just required the measurement probes to be placed at a point (1 m above the floor) nearest to the sitting respondent. Meanwhile the Class III protocol is based on simple measurement of indoor air temperature and relative humidity at one measuring point. The questionnaire survey for this class is treated as non-contiguous and independent with the physical thermal measurements unlike in protocol Class I and Class II.

In order to understand the outline of occupants’ thermal comfort expectations, several Class III models were reviewed. Humphreys as cited by Charles (2003) measured 36 sets of objective and subjective assessments from various countries suggested that thermal neutrality \( (T_n) \) is strongly depended on globe temperature \( (T_g) \) recorded inside the buildings:

\[
T_n = 2.56 + 0.83 T_g \quad \text{(Pearson correlation, } r = 0.96) \quad (2.3)
\]
Humphreys added that to predict comfort temperature ($T_{co}$) in naturally ventilated building against mean monthly outdoor temperature ($T_m$), the following equation can be used (Feriadi and Wong 2004):

$$T_{co} = 0.53T_m + 11.9 \quad \text{(Pearson correlation, } r = 0.97) \quad (2.4)$$

In a latter attempt to reanalyse Humphreys model, Auliciems had came up with a model that combine data from both buildings that are air-conditioned and naturally ventilated (Eq.2.5) (Feriadi and Wong 2004).

His comfort temperature ($T_{co}$) model is predicted in terms of mean indoor ($T_i$) and outdoor monthly temperature ($T_m$):

$$T_{co} = 0.14T_m + 0.48T_i + 9.22 \quad \text{(Pearson correlation, } r = 0.95) \quad (2.5)$$

Later, Humphrey examined people’s adaptation to their outdoor temperature. He then included the area’s monthly mean of outdoor temperature, $T_m$ to be analysed with naturally ventilated building and climate controlled building separately. The result is depicted in Equation 2.6 for naturally ventilated building:

$$T_n = 11.9 + 0.53T_m \quad \text{(Pearson correlation, } r = 0.97) \quad (2.6)$$

Further revision to the ASHRAE Standard 55 for naturally ventilated building suggests that outdoor climate environment for each building should be characterized in terms of mean outdoor dry bulb temperature, $T_{a\text{, out}}$ instead of the effective temperature (ET*) providing a simpler outdoor temperature expression that can be easily understood by designers and HVAC engineers (De Dear and Brager 2002).
Optimum thermal comfort, $T_{\text{conf}}$, for naturally ventilated building is thus estimated using the following equation:

$$T_{\text{conf}} = 17.6 + 0.31 T_{a,\text{out}}.$$  \hspace{1cm} (2.7)

Then, the range of temperature around $T_{\text{conf}}$ corresponding to 90% and 80% thermal acceptability for Malaysians is defined as 29.2°C and 28.7°C, respectively (Zain 2007). These percentages of acceptability are then applied with 0.5 and 0.85 values (PMV-PPD indications that a large group of subjects expressing mean thermal sensation vote) as a function of indoor operative temperature in order to produce 90 and 80% acceptable comfort zone, respectively.

### 2.2.2 Visual condition and perception: models and theories

In architecture, vision is vital because of its role to perceive both spatial relationships and details. Through visual experience, the process of communication via both the visual identification information sources and subsequent gathering and processing of detailed quantitative and quality information can be achieved.

The human eye can adapt remarkably to various lighting condition. The illumination at the eye during light exposure ranged from 3 to 9100 lux. However absolute illumination especially during daytime cannot be determined by the eye alone. During the day, because of the changing sky and sub condition, absolute illumination level is not reliable. In this case, by determining the size and position of windows, the proportion of the available daylight that will be admitted can be calculated. This indoor daylighting is usually expressed in terms of daylight factor. However in this study, the more appropriate daylight measuring method is through
daylight ratio calculation, which consists of indoor daylighting illumination against outdoor illumination collected from both indoor and outdoor measurement locations.

Daylight is described as the diffused lighting source from the sun in the daytime. The action incorporating daylight in building is known as daylighting. From the environmental perspective, the definition of daylighting includes the inherent ability to turn off the artificial lighting when not needed in the daytime (Ternoey 1999).

Visual comfort is the comfort state that is influenced by adequate amount of illumination in order to perform a task and without any discomfort glare intrusions. People’s visual comfort perception based on their day lit space can be surveyed using Hopkinson’s dark – bright scale (Hopkinson 1963). Meanwhile, the reaction to glare sensation can be obtained through the not noticeable - noticeable scale glare condition, as used by Iwata and Tokura (1998).

2.2.2.1 Why use Daylighting?

The use of daylighting was common to building designs throughout recorded history. However, in the 1950s fluorescent lighting, air-conditioning and other electricity usage combined to make a new commercial building paradigm, thus reducing daylighting implementation (Ternoey 1999). Daylighting has been proven to increase social, environmental and economic performance compared to standard construction with only artificial lighting.
The amount of daylighting in a building can be predicted using a formula that consists of three components, namely, sky component; external reflected component; and internal reflected component (Hopkinson 1963), where:

1. Sky Component: the light coming from the sky via windows directly illuminating the point without reflection on the way.

2. External Reflected Component: the light source which was reflected off external surfaces and penetrates into the interior via windows, for instance from the opposite façade, balconies, and window awnings.

3. Internal Reflected Component: the light reaching the point after reflected from various surfaces within a room.

In Malaysia, the high amount of daylight availability is enough to provide an indoor space with ample daylighting that is above 300 lux provided that windows for this particular room is not heavily shaded and / or obstructed by neighbouring buildings. Further explanation on the source of daylighting in Malaysia is included under the sub-heading 2.2.2.3.

2.2.2.2 Daylight Ratio measurement

The Daylight Ratio is used in obtaining the percentage ratio of indoor illumination level with its simultaneous outdoor illumination level. This type of measurement is viable in countries close to the equator, like Malaysia because the sun shines straight overhead in the afternoon most of the year. Figure 2.2 shows the solar
noon sun angles for the equator which ranges from 66.5° (June solstice) to 113.5° (December solstice) (Pidwirny 2006). The result from Daylight Ratio measurement is reasonably similar to the western recommendation values for visual comfort using the Daylight Factor calculation.

![Solar noon sun angles for the equator](Modified from Pidwirny, 2006)

In hot-humid climates the sky is typically overcast and its luminance is often above 7000 cd/m² which results in very bright proportion of diffused radiation when viewed from a moderately lit room. Due to this condition, it is meaningless to calculate the interior lighting in photometric illumination terms. Therefore the indoor daylight condition is measured using the ratio of the illumination to the simultaneous outdoor illumination, which can be taken as a constant (Koenigsberger 1974; Ibrahim 1999). This constant ratio is expressed as a percentage as shown in Equation 2.8:

\[
\text{Daylight Ratio} = \frac{\text{indoor illumination}}{\text{outdoor illumination}} \times 100 \quad (2.8)
\]
2.2.2.3 Source of Daylighting

Solar radiation is the source of daylight gained from the hemispherical vault. Solar radiation that passes through the atmosphere is composed of ultraviolet, visible and infrared radiation. The visible radiation (or light) with a wavelength that ranges from 400 to 700 nm is the only radiation that can be seen by the human eye. The longest wavelength is visible in red while the shortest can be seen in violet after refracting the light using a prism. Visible radiation is divided into two components, namely, diffused illuminance and direct-beam illuminance. Both of these components add up to form global illuminance.

The amount of illuminance in building is dependent on three parameters: the microclimate of the area, altitude of the sun, and sky condition. Countries near the equator receive more sunshine compare to their counterparts in either northern or southern hemisphere. In terms of sky condition, clouds and other elements like haze and dust particles screens the beamed radiation through the atmosphere. Cloud cover justification is shown in Table 2.2. Three types of skies with their cloud cover justification have been identified.

Table 2.2: Relationship between types of skies and the cloud cover justification.

<table>
<thead>
<tr>
<th>Type of sky</th>
<th>Cloud cover justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavily clouded sky</td>
<td>7.0 oktas &lt; cloud total &lt; 8.0 oktas</td>
</tr>
<tr>
<td>Intermediate sky (average cloudy condition)</td>
<td>1.0 oktas &lt; cloud total &lt; 7.0 oktas</td>
</tr>
<tr>
<td>Clear sky</td>
<td>0.0 oktas &lt; cloud total &lt; 1.0 oktas</td>
</tr>
</tbody>
</table>

Source: Malaysian meteorological department

During a clear sky condition, the sun is the brightest source of light. The clear sky model is divided into three luminance regions (Figure 2.3a). The first region is
known for its brightness and is located nearest to the sun. The second region is a very large area that covers much of the rest of the sky. This region also includes a relatively dark zone which is defined by the sun and the zenith point [90 degrees from the sun]. Meanwhile, the third region generally lies just above the horizontal all around the sky vault. Its brightness comes midway between the brightest and the darkest region. The atmosphere of the clear blue sky filters and diffused light but provides low illumination (Figure 2.3b). Although near the sun region has the highest brightness, the majority of the blue sky provides only 2,000 to 10,000 lx, which is less bright than the overcast sky.

The overcast sky condition occurs when the cloud cover completely obscures the sun. Diffused light is produced during this particular sky condition. The sky is brightest at the zenith and decreases at the horizon to approximately one-third of its maximum brightness as shown in Figure 2.4a and 2.4b (Egan 2002).
The Malaysian sky type has been identified as intermediate sky (Zain-Ahmed 2000; Zain-Ahmed 2002). Moreover, the Malaysian daylight design criteria is within ten to eighty kilolux during daylight hours from 8 am to 5 pm based on long term data collected from Subang International Airport meteorological station. The data was collected from 1975 to 1995 in the month of March, August and December. The sky illuminance range above ten kilolux consumes 77% of the working hours. Meanwhile another 16% of the working hour received sky illuminance that exceeds eighty kilolux bringing the total illuminance above ten kilolux to 93% (Figure 2.5). In this study, the daylight ratio and visual comfort measurements were conducted from 8 a.m. until 5 p.m., which corresponded to hours of daylight.
2.2.3 Acoustics condition and perception: models and theories

Acoustics comfort occur when a sufficiently ‘quiet’ environment to enable the task to be carried out comfortably and without distraction is met, i.e. with no unwanted sounds (noise) or vibration. Acoustics is also known as sound.

Noise, as sub discipline of acoustics can be described in terms of two key parameters, namely, frequency and wavelength. These parameters are quantities that describe the nature of pressure fluctuations in a medium, i.e.: air, which is eventually interpreted as sound in the brain. Both of the parameters are influences by the speed of sound, direction of sound travel and the time that sound arrives at a listeners’ ears (Cowan 1994).
Noise can affect people in different ways depending on its level, where it varies from simple annoyance to actual hearing damage (CIBSE 2006a). The three main potential problems are as follows:

i. **Annoyance**: where the noise is noticeable and can affect concentration

ii. **Masking**: where the noise effectively covers or masks another wanted sound, for example speech can become masked by road traffic or machinery noise causing interference to speech intelligibility

iii. **Hearing damage**: where the noise is loud enough to cause temporary or even permanent hearing damage

The acceptable level of noise depends on four factors, namely, objective; subjective; physical; and psychological factors. Whether noise is disturbing or not is influenced by the state of mind or expectation of the listener. For instance, in a train, the monotonous noise of 70 to 80 dBA is not disturbing, but in a quiet home, at a certain circumstance even the ticking of a clock at 20 dBA may cause annoyance (Koenigsberger 1974). In general, the decibel scale for sounds is shown in Figure 2.6 (Rubin 1980).
People’s noise annoyance level can be obtained by applying scales to annoyance categories. A typical noise annoyance question is: ‘How would you describe your general feelings about the aircraft noise in this neighbourhood? Would you say you are: (1) not at all annoyed; (2) slightly annoyed; (3) moderately annoyed; (4) considerably annoyed; or (5) highly annoyed?’ (Fields 1993; Miedema and Vos 1999). Due to the question’s straightforward nature, which can be easily understood by a lay person, the author has decided to adopt the particular question style and its scale of annoyance categories.
2.2.3.1 Decibels

Sound level is defined through decibel. One decibel of sound level is defined from:

\[ L_W = 10 \times \log \left( \frac{W}{W_{\text{ref}}} \right) \]

(2.9)

where,
- \( W \) is the measured power
- \( W_{\text{ref}} \) is a reference power, usually \( 1 \times 10^{12} \) W
- \( L_W \) is the sound power level

However, in this study, as most studies have done, noise is assessed using sound pressure level (SPL). SPL is proportional to sound power; it can be denoted in terms of decibels and is defined as:

\[ \text{SPL} = 10 \times \log \left( \frac{P^2}{P_{\text{ref}}^2} \right) \]

(2.10)

where,
- \( P \) is the measured acoustic pressure
- \( P_{\text{ref}} \) is the reference pressure of \( 2 \times 10^{-5} \) N/m²

Because the log of 1 is 0 \((10^0 = 1)\), the SPL = 0dB when the acoustic pressure is the same as the threshold of hearing. In other words, SPL corresponds to human’s healthy hearing mechanism.

2.2.3.2 Weighting networks and equivalent level \( (L_{\text{eq}}) \)

Weighting networks are filters in sound level meters that vary frequency sensitivities according to set standards. Normal human hearing range is between 20 Hz to 20 kHz, especially between 200 Hz and 10kHz (CIBSE 2006a). There are four known weighting networks available, namely, A-, B-, C- and D- weighting. The most common weighting networks used are the A- and C-weighting networks. A- and C-weighting networks are sensitive to SPL from 0 to 70 dB and above 90 dB,
respectively (Cowan 1994). In 1930s, A-weighting was agreed to be used to measure low sound pressure levels, while C-weighting was to measure the opposite. When it comes to assessing noise, A-weighting or dBA is the unit of choice, because it simulates the frequency sensitivity of the human hearing mechanism.

Because the noise levels continuously rise and fall it is difficult to evaluate it. In order to make things easier, the equivalent level was defined as a continuous sound level that would produce the same effect on the human ear if compared to the actual noise observed during the measurement, with all the variations. Therefore, the $L_{eq}$ can substitute by a single value all the variations of the noise level. The equivalent sound level is presented in dBA units (Cowan 1994; Zannin 2003).

### 2.2.3.3 Sound propagation

In order to understand how sound travels into buildings from the outdoors, it is vital to know its propagation behaviour. Both light and sound have similar properties but are based on different types of energy. The difference between light and sound is that, light is typically described in terms of its wavelength, whereas sound is typically described in terms of frequency.

Sound travels over a distance of more than 200ft in air. Four principal methods are known to change direction of sound propagation through air, namely, reflection, refraction, diffraction and diffusion, which are similar to light as well. These phenomena occur when a sound wave encounters a change in medium, temperature, humidity or wind currents. Reflection of sound occurs when the sound wave is bounce off a surface at the 90 degree angle. Refraction of sound is described as the bending of
sound wave caused by propagation through various medium or into a different condition in the same medium, which changes the speed of sound. For example, when sound travels through the atmosphere, temperature, humidity and wind current conditions, it changes because the speed of sound in air is dependent on these factors.

The refraction phenomenon is usually in evidence in large outdoor areas. Two different atmospheric conditions are identified, firstly, when the air temperature near the ground is warmer and secondly, when it is cooler. For the first condition, the sound generated at ground level would bend upward towards the cooler air, which leaves a shadow zone (i.e.: less audible zone) over the person listening (Figure 2.7a). Warmer ground temperature results in evaporation, which changes the medium in which sound is travelling hence, makes sound more audible at higher altitudes. When this occurs, a sound source may be visible at a distance but quieter than expected. The most common example would be when a desert mirage occurs. This particular condition can also occur in a typical summer afternoon or in hotter climate countries. Heightened sound occurrences at higher altitudes measured in multi-storey buildings will be discussed in Chapter 7.

For the second condition, the sound wave bends downward toward the ground and usually got reflected (if the ground is reflective, i.e.: over calm lake or icy surfaces) off the ground and hops along to propagate much farther than expected (Figure 2.7b). This condition occurs when the air is cooler close to the ground than it is at higher altitudes. Contrarily to the first condition, even a quiet conversation may be heard from opposite ends of for instance a lake as a result of the latter condition. Due to study limitations, this particular condition is not monitored.
Wind current also allows sound to be propagated less farther than expected when the source is emitting sound against the direction of wind travel (upwind) (Figure 2.8a) but propagates farther when the source is emitting in the direction the wind (downwind) (Figure 2.8b). Similar to the condition illustrated in Figure 2.7a, a person standing in the shadow zone is less exposed to the sound.

(a) (b)
Figure 2.7: The effect of temperature variations on sound propagation direction. The shaded area is the shadow zone.
Modified from Cowan, 1994.

(a) (b)
Figure 2.8: The effects of wind currents on sound propagation direction. The shaded area is the shadow zone.
Modified from Cowan, 1994.
2.3 Design features of naturally ventilated and lit buildings

2.3.1 Building orientation

The movement of the sun for Kuala Lumpur is shown in Figure 2.9. From the sun path, it shows that all facades of any particular orientation are exposed to direct-beam radiation at some stage throughout the year. However, the maximum exposure to direct-beam radiation will occur on the western and eastern facades. North facing facades received the lowest amount of direct-beam radiation all year. It is suggested that north facing room had the shortest range of direct-beam depth compare to other room orientations (Syed Fadzil 2002; Syed Fadzil 2003).

Figure 2.9: Kuala Lumpur's Sun Path
Modified from (Laar 2002)
2.3.2 Room reflectance for optimise daylighting usage

The illumination distribution of a room is highly based on the room’s surface reflectance. The Illuminating Engineering Society of North America (IESNA) guideline as quoted by Egan and Olgay (2002) suggested the minimum reflectance for ceiling; walls and floor are 70, 50 and 20%, respectively. Ceiling has the highest value because it is the most suitable surface to reflect light especially in deep, wide, side-lit rooms. Figure 2.10 shows the relationship between the task illuminance based on light proportion in a room with various surfaces. The percentage shows illuminance relative to all white surface conditions is rated at 100%.

![Figure 2.10: Surface reflectance opposite a window wall](modified from Egan and Olgay, 2002)
2.3.3 Window design features

The transmittance of a material is affected both by the surface conditions and the absorption within the material. Material such as clear glass transmits light with a minimum distortion or spread and is more stable against chemical degradation than plastic materials (Figure 2.11). In order to optimise daylight transmittance, windows are designed with glare-free and high transmittance value. This means that windows in domestic setting should be designed with clear glass rather than tinted or coated with reflective mirrored film. The reason behind this is to retain the quality of daylight into an indoor space.

![Figure 2.11: Direct and diffuse solar radiation transmittance through glass. Modified from Egan and Olgay, 2002](image)

Large window opening size and high headroom are needed to ensure optimum daylighting (Guzowski 1999). In Malaysia, the minimum window area requirement is 10% based on a room’s window to floor ratio (that is, window area/ floor area x 100) in order to allow for daylighting. The window opening area should be no less than 5% of the window to floor ratio in order to allow for natural ventilation into a room. These minimum requirements can only be applied to an interior space that is not air-
conditioned (Malaysia 2003). Moreover, an analysis by Zain-Ahmed et al. found that the appropriate window to floor ratio is 40%. This allowed above 300 lux, which is the minimum requirement of illumination in a non-residential building through daylighting (MS1525 2001). It also reduces energy consumption of electric lighting (Zain-Ahmed 2002).

Three basic forms of openings for admitting daylight indoor are identified, namely, through sidelighting, toplighting and atria. The characteristic for each of the forms is described in Figure 2.12.

![Figure 2.12: Characteristics of sidelighting, toplighting and atria. Modified from Egan and Olgay, 2002](image)

This study focuses on sidelighting strategy because it is widely used in typical multi-storey dwellings in Malaysia. In order to reduce the effect of glare discomfort,
the surrounding surfaces' reflectance adjacent to the window should have relatively high luminance. This can be performed by installing more than one window in a room, which can contribute in reducing the contrast level of the indoor condition against the sky.

Figure 2.13 shows the illumination gradient based on three opening locations, namely, upper, middle and lower window during both overcast and sunny skies. In this study, sunny sky is referred as clear sky. During the overcast sky, the upper window has the best light distribution because the light transmission comes from the zenith. However during clear sky, the upper window does not provide the best light distribution. Egan and Olgay (2002) added that in any weather condition, the upper window can admit very bright light without glare. In the case of middle window, it is commonly used to provide for views. At this location, this particular window does not give optimal daylight distribution despite any sky conditions. Meanwhile the lower window provides optimal distribution of reflected sunlight (during clear sky). This is because the distance between the reflected light source and ceiling is maximised. In which case, the light level is lower near the window wall but increases slightly higher in deeper spaces.

![Figure 2.13: Illumination gradient showing at section view based on three opening locations. Modified from Egan and Olgay, 2002](image-url)
2.3.4 Issues of building material usage in Malaysia

Another method to promote indoor comfort is by designing a building using materials that have thermal mass properties suitable to the local climate context of a site. The mean outdoor temperature during the day in Malaysia is 30°C (s.d. = ±2.6°C) while the mean night temperature is 26°C (s.d. = ±1.7°C) (Zain 2007). This scenario is experienced throughout the year. In order to reduce heat gain, buildings in Malaysia should have materials with thin thickness and vertical building surfaces should be in locations that are not exposed to solar radiation, for example, shaded by long roof overhangs.

Existing typical multi-storey hostels in Malaysia are built using reinforced concrete structures and brick walls. In this country, the presence of high thermal conductive value can increase indoor discomfort. In order to improve the indoor thermal condition, more windows for cross ventilation are introduced. However, alternatives using thinner thickness materials can be quite costly and do not meet the budget constraints of a medium low cost dwelling project, such as a public university’s multi-storey student hostel.

2.3.5 Balcony design potentials

Another design feature that promotes passive energy usage is via the use of projected balconies. Projected balconies located at the windward side of a building are suggested to be effective in promoting natural ventilation into the building. Simulations by Piranto and Depecker (2002), and Chand et al. (1998), revealed that the air that enters the indoor reaches maximum speed and spreads into the living area. Piranto and Depecker (2002, 2003) also added that projected balcony can function as
a shading device from excessive solar radiation exposure. Another advantage of having a balcony is to screen external noise. Results from simulations found that when the noise source is close to the projected balcony, the reflections from the upper balconies and the screening effects of the balcony floors have major contributions to noise loss (Cheng 2000; Hossam El Dien and Woloszyn 2004; Tang 2005). Projected balconies with opaque front panels (such as concrete) become the determinant member of the balcony affecting the A-weighted noise loss. The balcony without a front panel does not offer any noise screening (Tang 2005).

In a field measurement conducted in Korea, Lee et al. (2007) found that sound pressure levels in most floors of apartments with projected balconies were less than 65 dBA, which was in accordance to Korean legal limit of exterior noise (Lee 2007). Furthermore, the maximum level of traffic noise was detected in the upper floors of the building; but, the noise difference between each floor was not large. Similar to a projected balcony, roof overhangs may also function as wind scoops as well as providing adequate protections for rain and glare.

2.4 Influences of architectural features on occupants' indoor comfort perceptions

2.4.1 Architectural systems approach

In architecture, the systems concept is not directed to a particular case as an individual phenomenon, but to imply to the total pattern of phenomenon that create an environment (Stanford 1965). A building is a system that is consisted of interconnected complex functionally related components designed to accomplish a particular goal and is not to be referred as a mass, static and timeless entity, but rather
to look at it as a series of events. (Handler 1970). Handler added that a building can be evaluated and considered in various systems approach, such as: occupants’ activities, the functionality of building components, structural members interacting with one another, building materials weathering and decaying, and buildings interaction with its natural and man made environment (Handler 1970). Building is treated as an open system similar to an organic system. This is because, like organic system, a building is maintained by constant steady-state of ever-changing matter and energy flow (i.e.: entering and exiting it) or also known as entropy. Closed system is described in reaching equilibrium and more towards increasing the entropy. This type of system is static (Clayton 1996).

Human performance plays an important role in the architectural system. Human performance is the reason for building goals and technical standards to be enforced. This is because the effects of illumination, thermal and sound level on humans as occupants determine the ultimate evaluation of buildings (Handler 1970). In evaluating the building’s performance on its occupants, systems analysis allows a systematic feedback control method to take place in a simplified manner. The basic idea of the feedback concept in system consisted of first, a receptor (e.g.: sense organ like eyes, ears and skin); second, the message (e.g.: sensations through environmental condition); third, the control apparatus (e.g.: the brain) and fourth, the effector (e.g.: muscle which responds to the incoming message). Finally, the functioning of the effector is monitored back to the receptor, which makes the whole process self-regulating and stabilization is guaranteed (Bertalanffy 1968). Figure 2.14 shows a simple feedback scheme.
It is important for architects and systems researchers to detect occupants’ feedback towards their building performance especially in if there is a case of over designing a heating or cooling system. Even though certain performance standards are met, but other building goals from the total system like costs and reducing occupants’ indoor comfort could occur.

Because of its ability to conceptualise, group and analyse alternatives, architectural systems approach is therefore important in order to identify hostel occupants’ indoor comfort perceptions based on multiple factors.

2.4.2 Occupant’s behaviour in buildings

In this study, occupants’ feedbacks are assessed through the semantic differential tests. Unlike the one commonly used in psychology, such as the one introduced by Osgood (1957), the descriptions for the semantic differential test are selected from words which occupants use to describe or comment on buildings rather than entirely judged on people’s intelligence towards linguistic understanding. Descriptions modified however, still bear some relationship to Osgood’s by aiming to
identify the tested variable through evaluation, activity and potency dimensions. The examples for each dimension are as follows:

1) Evaluation dimension: Pleasant-unpleasant; satisfied-dissatisfied.

2) Activity dimension: Hot-cold; active-passive; fast-slow.

3) Potency dimension: Strong-weak; large-small; heavy-light; agree-disagree

Scientifically, occupant’s behaviour to their building interiors can be measured in identifying the effects produced by occupant-indoor conditions interactions. Indoor conditions in this case are referred to as independent variables that can be analysed via Analysis of variance (ANOVA). ANOVA is a common analysis to understand and explain variations between variables. For example, when occupants in Malaysia are asked to rate their thermal sensation between two non-air-conditioned rooms: one with a large skylight roof and the other with small windows and long overhangs; given the occupants are aware of their warm indoor condition, most likely they will perceive the latter room to be cooler. The pattern of responses for the mean differences between the rooms will indicate whether there is any interaction between large fenestrations and indoor thermal condition in the effects they produce. Application of the semantic differential used in this study will be explained in the Chapter 4.

Occupants’ responses in the above example can be explained using the idea of perceptual judgment. Perception is experienced by means of our sense organs (e.g.: visual perception using the eyes and auditory perception when using the ears). It is important to know that the occupant’s indoor comfort perception not only deals with thermal sensation but also includes other areas such as lighting, acoustics and internal
gains (Ward 2004). In other words, occupant’s indoor comfort perception is an active reaction that cannot be isolated to only a single sense organ (Canter 1974).

Summary of Review

Based on the literatures reviewed in this chapter, several assumptions have been identified. The following assumptions are considered relevant according to Malaysian typical multi-storey hostel with local college-aged subject context:

1 Thermal condition and perception

1.1 Operative temperature is recommended to be suitable in measuring warmth for human indoor comfort.

Based on the review, operative temperature measurement has been selected as the most suitable method to predict occupants’ thermal comfort staying in typical concrete dwellings with low natural air speed circulation. In order to complement this type of measurement, other types of indoor climate monitors, such as, air temperature, relative humidity, air speed and ping-pong ball globe thermometer were associated as well. The measurement protocol used in this study was an adaptation to protocol Class II of thermal comfort measurement as mentioned earlier in this chapter (i.e.: sub heading 2.2.1.4). Modification made to this protocol was by conducting the questionnaire survey independently. This decision was made because the questionnaire survey includes not only thermal comfort surveys but also incorporates visual, acoustics, and overall indoor comfort perception surveys.
1.2 Darker skin people are revealed to be more tolerable to hotter weather condition than people with fairer skin.

This argument is considered useful in this study due to the fact that the locals in Malaysia, consisting of three major ethnic groups, namely, Malays, Chinese and Indians have darker skin thus making them more tolerant to hot weather condition.

1.3 Most thermal comfort investigations correlate outdoor air temperature with operative temperature in order to predict thermal comfort.

Findings from other thermal comfort Class III data (De Dear and Brager 2002; Charles 2003; Feriadi and Wong 2004) suggested that the indoor thermal condition is highly associated with their outdoor thermal condition. In this study, the relationship between outdoor and indoor temperatures is examined because typical multi-storey hostels in Malaysia are naturally ventilated which suggested that the indoor thermal condition is strongly dependent on the outdoor temperature.

2 Visual condition and perception

2.1 Overcast sky is revealed to be brighter than clear sky because it receives diffused light through the maximum brightness from the sun. During clear sky the zenith is not the brightest area that resulted in lower illumination level than during overcast sky.

2.2 Daylight measurement in countries near the equator like Malaysia that has more than 7000 cd/m² level of luminance, is recommended to use the Daylight Ratio model.
2.3 Daylighting strategy is suitable to be implemented in Malaysia. This is because the average total illuminance is above 10 Kilolux for about 93% from 8am to 5pm.

3 Acoustic condition and perception

3.1 The level of noise to be considered disturbing is influenced by the expectation of the listener.

It can be assumed that the student occupants from selected hostels exhibit different tolerance to the noise level that occurred based on the task she performs. For instance, if she is studying, the noise level in tolerance would be very high compared to when she is entertaining friends in her room.

3.2 Warmer ground temperature bends sound upward making sound more audible at higher altitudes.

The measured rooms located on the top floor of selected hostels are expected to receive more noise level from external sources compared to the ones located on the lower floors.

3.3 Wind current enables sound to propagate farther from its source.

Based on this argument, it is considered necessary to analyse wind direction and wind speed at the selected hostels obtained from Malaysian Meteorological Department.
4 Design features of passive energy building

4.1 Interior spaces facing north receive the lowest direct-beam radiation.

The author assumed that lower indoor temperature and daylight ratio would be experienced in measured rooms facing the north compared to the other measured rooms facing other orientations.

4.2 Higher surface reflectance factor for surfaces adjacent to window could reduce the effect of glare discomfort.

Surface reflectance factor in measured rooms are estimated using the IESNA guideline (Egan 2002).

4.3 Illuminance level is lower near the window wall but increases slightly higher in deeper spaces.

Referring to this finding, the author decided to observe the characteristic of daylight ratio during different cloud cover patterns.

5 Occupants’ behaviour in buildings

5.1 Occupants’ behaviour can be examined using semantic differential test in reference to their indoor climate condition.

The semantic differential tests used in this study are adapted from Fanger’s thermal comfort (De Dear 1994), Hopkinson’s visual comfort (Hopkinson 1963), glare annoyance (Iwata and Tokura 1998), and noise annoyance scales (Fields 1993; Miedema and Vos 1999).
5.2 Occupants' perceptual judgement cannot be regarded as isolated response that only concentrates on one particular indoor environment.

Findings from the above investigations encouraged the author to focus on examining occupants' overall indoor comfort perceptions based on their individual votes on physical indoor climate conditions.

**Summary of Chapter**

This chapter provides the review of fundamental issues on: (1) thermal, visual, acoustics comforts, (2) design features of passive energy building and (3) human behaviour in building in relation to the research scope. In the light to understand how the models and theories are applied, recent investigations on the performance of building envelope, thermal, visual and acoustics comforts are discussed in the following chapter.
CHAPTER 3

REVIEW OF INDOOR COMFORT POTENTIALS

3.1 Introduction

This chapter provides reviews of studies related to the scope of research mentioned in Chapter 1. The review is constructed according to the objectives below:

i. To review investigations on the indoor thermal environment.
ii. To review investigations on the indoor visual environment.
iii. To review investigations on the indoor acoustics environment.
iv. To review investigations on integrated indoor comfort factors.

3.2 Thermal comfort

3.2.1 Thermal comfort investigations in summer and hot climate countries

Evidences from thermal prediction conducted in hot climate countries can be under-predicting. This was because models were developed in climate chamber experiments that widely differ from actual thermal conditions (Fountain 1996; Brager 1998). Thermal comfort field assessments and model predictions conducted in naturally ventilated buildings during summer and hot climate countries are shown in Table 3.1. In terms of climate, studies listed show that the observed neutral temperatures in buildings located in hot climate countries are higher than the ones predicted and their outdoor temperature (Abdul Rahman and Kannan 1996; Baker and Standeven 1996; Brager 1998; Kwok 1998; Feriadi and Wong 2004; Sh.Ahmad 2005;
Ji 2006; Zain 2007; Dahlan 2008) compared to the ones in temperate countries (Oseland 1998; Zhang 2007). Explanation of equations used in Table 3.1 was explained in Chapter 2.

Results of these studies suggested that people can acclimatise to their indoor surroundings based on wider temperature range reported compared to the ones that were modelled. In sum, the acclimatisation means are uncertain and also not influenced by PMV's six factors, namely, indoor air temperature, relative humidity, airspeed, metabolic rate, clothing insulation and mean radian temperature.
### Table 3.1: Summary of thermal comfort experiments between observed and predicted neutralities in relation to outdoor climate in naturally ventilated buildings.

<table>
<thead>
<tr>
<th>Location &amp; season</th>
<th>Authors</th>
<th>Mean outdoor temperature (°C)</th>
<th>Neutral Temperature (°C)</th>
<th>Observed neutrality</th>
<th>Predicted mean vote/ Comfort temperature model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bangkok, summer</td>
<td>Busch (1992), cited in Barger &amp; De Dear (Brager 1998)</td>
<td>28.6</td>
<td>28.5</td>
<td>25.1 (PMV, Eq.:2.2)</td>
<td></td>
</tr>
<tr>
<td>England, summer</td>
<td>Oseland (Oseland 1998)</td>
<td>18.0</td>
<td>21.1</td>
<td>24.1 (PMV, Eq.:2.2)</td>
<td></td>
</tr>
<tr>
<td>Hawaii, Hot season</td>
<td>Kwok (Kwok 1998)</td>
<td>30.0</td>
<td>29.5</td>
<td>28.0 (Eq.: 2.4)</td>
<td></td>
</tr>
<tr>
<td>Singapore, summer</td>
<td>Brager &amp; De Dear (Brager 1998)</td>
<td>27.1</td>
<td>28.5</td>
<td>25.7 (PMV, Eq.:2.2)</td>
<td></td>
</tr>
<tr>
<td>Brisbane, summer</td>
<td>Brager &amp; De Dear (Brager 1998)</td>
<td>24.9</td>
<td>25.6</td>
<td>25.0 (PMV, Eq.:2.2)</td>
<td></td>
</tr>
<tr>
<td>Shanghai, summer</td>
<td>Ji et al (Ji 2006)</td>
<td>28.5</td>
<td>29.0</td>
<td>26.6 (Eq.: 2.7)</td>
<td></td>
</tr>
<tr>
<td>Athens, summer</td>
<td>Baker &amp; Standeven (Baker and Standeven 1996)</td>
<td>-</td>
<td>30.5</td>
<td>29.5, but then corrected to 28 due to local increase in airspeed from 0.1 to 0.2m/s.</td>
<td></td>
</tr>
<tr>
<td>Indonesia</td>
<td>Feriadi &amp; Wong (Feriadi and Wong 2004)</td>
<td>27.3</td>
<td>28.8</td>
<td>26.4 (Eq.: 2.6)</td>
<td></td>
</tr>
<tr>
<td>Hunan, spring</td>
<td>Zhang et al (Zhang 2007)</td>
<td>20.9</td>
<td>21.5</td>
<td>24.8 (PMV, Eq.:2.2)</td>
<td></td>
</tr>
<tr>
<td>Klang Valey, Malaysia</td>
<td>Abdul Rahman &amp; Kannan (1996)</td>
<td>29.9</td>
<td>25.5 − 28.5</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Klang Valey, Malaysia</td>
<td>Sh.Ahmad (Sh.Ahmad 2005)</td>
<td>27.4</td>
<td>-</td>
<td>26.1 (Eq.: 2.7)</td>
<td></td>
</tr>
<tr>
<td>Klang Valey, Malaysia</td>
<td>Zain et al (Zain 2007)</td>
<td>27.3</td>
<td>-</td>
<td>26.2 (Eq.: 2.7)</td>
<td></td>
</tr>
<tr>
<td>Klang Valey, Malaysia</td>
<td>Dahlan et al (Dahlan 2008)</td>
<td>27.8</td>
<td>30.9</td>
<td>25.7 (PMV, Eq.:2.2)</td>
<td></td>
</tr>
</tbody>
</table>

*Note: (-) indicating data not available.*
Other works stressed that weak representation of occupants’ thermal comfort was due to non-precise parameters, namely, metabolic rate and clothing insulation estimations through computer and analytical simulations (Zhang 2001; Havenith 2002). Despite estimating these parameters based on ISO7730 (ISO7730 2006), metabolic rate and clothing insulation can also be produced in climate chambers but it would not guaranteed exact resemblance with actual environment and also are more complex to conduct (Brager 1998). In another comfort living proposal, thermal comfort factors were complemented with visual and acoustic comfort as well but it was not tested on subjects (Oral 2004).

In Japan, Nakano and co-workers (Nakano 2002) investigate the neutral temperature between Japanese and non-Japanese workers (largely from U.S.A and Australia) in an air-conditioned office building. The largest difference was observed between Japanese female and non-Japanese males, reaching 3.1°C. They suggested that dress codes, type of worker (either sedentary or took part in stock trading) and different office temperature expectations were believed to be the causes. Although Japanese female workers wore lighter clothing insulation clothing than male workers, it was still unlikely to be a substantial factor for the large difference. The more likely factors were because non-Japanese males engaged in more mentally stress works (stock trading) compared to the locals (desk works). Non-Japanese males were also used to cooler indoor operative temperature in their offices, i.e.: 23.5°C in summer and 22.5°C in winter than the locals that were used to office temperatures between 24.5°C to 25.0°C. Even though this study focuses on the female subject only, Nakano’s work establishing that the level of activity and clothing type are important
in identifying occupants’ acclimatization method in achieving thermal comfort remains relevant.

3.2.2 Cooling strategies

Thermal comfort investigations done by Cheng and Ng in naturally ventilated dwelling buildings during summer predicted that airspeed can influence occupants’ thermal comfort (Cheng and Ng 2006). Three airspeeds i.e., 0.3, 1.0 and 1.5 m/s were simulated. 7000 field observations from 27 naturally ventilated buildings comprised of 13 countries were analysed. Mean outdoor temperature for all the selected samples is 23.8°C with standard deviation ±5.2°C, which closely resemblance Hong Kong’s meteorological record in 2002, i.e., 24.3°C and standard deviation ±5.0°C. Their finding via adaptive modelling suggested that airspeed around 0.3 m/s with air temperature of 29.5°C would likely satisfy the thermal requirement of 80% of occupants in Hong Kong during summer. Mallick (1996) also agreed that airspeed 0.3 m/s and greater increases thermal comfort. These works are considered relevant to this study in terms of their similar climate context.

Window opening positions can also affect occupants’ thermal comfort (Prianto and Depecker 2003). Prianto and Depecker found that pivoted window in upward position with opening angle of 45° increased the airspeed by about 19% compared to angle of 30°. PMV value for occupants (activity=1 met) in room with both window models are found to be +0.62 (slightly warm) for angle of 45° and +0.35 (neutral) for angle of 30°. It provides 0.27 of mean vote different and improves a comfort level. In another investigation, Rijal et al (2007) reported that occupants’ behaviour to open windows in their working area is influenced by their thermal comfort. From 219
subjects, 69% opened their window during summer, while only 14% opened their windows during winter. The studies done showed that occupants tend to open their windows more often during summer than during colder seasons. This finding is considered relevant to Malaysian climate context, where opening windows are usually associated with releasing indoor heat.

Window opening and passive energy heat transfer investigations are often associated with window to wall ratio and shading ratio calculations (Chow and Chan 1995; Liping and Hien 2007; Yu 2008). Window to wall ratio is basically the ratio of window area to its overall window wall area, meanwhile the shading ratio is the ratio of overhang depth to window height. In their investigation, Chow and Chan tested several window-to-wall ratios from 0.1 to 0.9 and plotted them against relative chiller load in high-rise buildings of Hong Kong. The window to wall ratio had a positive effect, which suggested that an increase in window to wall ratio increased the chiller load due to thermal storage effects. Meanwhile, values of shading ratio from 0.1 to 0.9 were plotted against solar load gained indoors. The solar load decreased as the shading ratio increased. More solar load reduction effect were detected for walls facing south and south-west, while lower reduction were detected for walls facing north and north-east (Chow and Chan 1995). Moreover, another study in Singapore found that north and south facing facades can provide much comfortable indoor environment than east- and west-facing facades. The optimum window to wall ratio recommended was of 0.2 to improve indoor thermal comfort for full-day ventilation and 600 mm horizontal shading devices are needed for each orientation in order to improve thermal comfort indoors (Liping and Hien 2007).
Another way to reduce heat stress indoor is through the usage of fans. There are three types of fans used to increase air velocity in buildings, namely, the ceiling fan, exhaust fan, and wall fan. Open commercial areas in hot climate countries, usually employed all three types of fan at the same time. Simulation by Wong et al. (2006) on hawker centres in Singapore suggested that to improve the thermal conditions, the exhaust fan should be installed in the cooking area meanwhile the wall fans should be installed in the eating areas. The usage of ceiling fans produced little effect to reduce customers’ thermal comfort due to their farther distance from the customers compared to wall fans. Ceiling fans are mostly used in dwellings or offices where the headroom is around 3m high (Mallick 1996; Lowe’s 2008).

In dense urban situations, where air flow through open windows is not always possible, a ceiling fan is a reliable source for cooling with low capital and running cost (Mallick 1996; Raja 2001). In Iran, a 10 storey building with total floor area of 8000 m² has the peak heating load of 1590 kW and the cooling load of 2028 kW. With the use of ceiling fans in each room, the peak heating and cooling demands of the building were reduced to 225 kW and 760 kW, respectively (Ehyaei and Bahadori 2007).

3.2.3 Climate chamber experiments

Under a more controlled environment, several environment chamber studies were reviewed. Kimura et al. had exposed 172 subjects (Japanese college-age persons) in a three hour thermal environment test (Relative humidity range = 40 to 80%; Mean air velocity range= 0.13 to 1.63 m/s; clothing range= 0.4 to 0.6 clo) (Tanabe 1987; Kimura 1994). Findings showed that increased air speed was inversely
related to the clothing range under low relative humidity. Suggestions have been made to increase the air speed indoors for seated occupants during summer in order to reduce air-conditioning usage.

Experiments in climate chambers however gave strong correlation with predicted thermal sensation votes and operative temperature compared to those observed within naturally ventilated buildings (De Dear 1994; Fountain 1996; De Dear 2004). To revise this notion, Oseland (1995) conducted thermal sensation vote surveys under three different environments; namely, in a climate chamber 18 – 26°C, at subjects’ home and their offices but these experiments were done during winter. It showed that participants felt warmer in their home than their office and warmer in their offices than in the climate chamber even when the indoor climate, clothing type and activity type were similar. Ironically, they reported neutral temperature in homes that were 2.2 °C lower than in the chamber and in offices it was 0.7 °C lower than in the chamber under steady-state conditions. It was suggested that by allowing occupants to adapt to their environment by reducing the thermoregulatory constraints (e.g. dress restrictions) and offering them individual control of temperature therefore appears to be the optimum strategy for energy efficient and comfortable buildings.

Gender differences effect in expressing thermal comfort can be divided into two types of studies. Earlier studies from 1940s to 70s generally support Fanger’s assumption that males and females had almost similar neutral temperature (Charles 2003). More recent studies in the 90s and until 2002, found that there were slight higher neutral temperature for females. In their climate chamber experiment Kimura et al (1994) with a sample size of 64 college-age persons (32 males and 32 females)
found that female subjects showed lesser total evaporation heat loss per-unit skin surface area about 0.4 and 1.3 when the chamber was set at 27°C and 30°C, respectively. This was because female subjects had lesser evaporation loss from their skin surface compared to male subjects.

In Australia, Cena and De Dear (2001) found that female workers in climate controlled offices tend to express more unacceptable thermal dissatisfaction than the male workers in summer season. The difference between female and male was 0.06 sensations unit, with males being cooler than the females. Parsons (2002) also found that female subjects in a climate chamber experiment showed more discomfort to cold environment than male, but tend to display close thermal comfort votes in warmer environment. Both genders were asked to wear similar clothing type (about 0.8 clo value). Parsons suggested that the greater sensitivity (physiology and psychological) to cold stimuli, less tolerance of cold discomfort and more adjusting clothing restrain were the reasons why females reported cooler sensation than males.

**Summary of Review**

After reviewing the studies related to thermal comfort investigations in summer or hot climate countries for passive energy buildings, it can be assumed that:

1. **Acclimatisation of thermal comfort is higher than the one predicted using ISO 7730’s PMV. Comfort temperature is around 26 to 31°C in hot climate countries based on Table 3.1.**
2. Improving the air speed above 0.3m/s indoor can increase occupants’ thermal comfort, which can be conducted through, opening windows and switching on ceiling fans.

3. Architects can contribute to indoor thermal comfort through passive energy strategy design, such as designing optimum window to wall ratio, and shading ratio in order to reduce solar gains.

4. Occupants’ thermal comfort can be achieved in terms of lessening thermoregulatory constraints (e.g. dress restrictions, allowing them to take cold drinks and etc.) and offering them individual control of temperature.

5. Female occupants are more sensitive to cool indoor condition compared to male occupants making it more important to design according to the female occupants.

3.3 Visual comfort

3.3.1 Visual comfort from daylighting through side-lit windows

Adjustments of daylight and sunlight level for indoor illuminance are highly variable with seasonal, diurnal, and weather conditions. In offices, daylight can be a source of variation in indoor light level. Consequently, most buildings allow additional artificial lighting and means of daylight controls, namely, blinds and curtains (Boubekri 1991; Boubekri 1993a; Boubekri 1993b; Velds 2002; Lindelof and Morel 2006; Nicol 2006; Sutter 2006). Typical illuminance level for climate controlled offices is 500 to 1500 lux (Begemann 1997; Mui and Wong 2006).

Shahriar and Mohit (2007) have estimated the daylight zone in typical office rooms in Malaysia using the Waldram Diagram and CIE Standard General Sky
Review of Indoor Comfort Potentials

equation. The dimension for the experiment office model is 12.6m (length) x 6m (width) x 2.63m (height). Its window to wall ratio is 20%. Plotted during 11 December at 8 am, which is the lowest level of illuminance for Malaysia, the depth for 300 lux is 3.5m and for 500m lux is 3m. In a field measurement conducted by Dahlan (2006), 3 libraries reading areas in the Klang Valey, Malaysia. Each reading area had different window to wall ratio, i.e.: 20% (Library 1), 40% (Library 2), and 80% (Library 3). Library 1 has the least daylight penetration with illumination not exceeding even 180 lux, which was lower than the minimum recommendation of indoor daylight illumination level: 300 lux (MS1525 2001). 500 lux of daylight zone for Library 2 exceeds up to 4m the reading area’s depth. Meanwhile in Library 3 at least 600 lux is available at 7m from the window. These findings are in good agreement with Zain-Ahmed et al (2000, 2002) that suggest daylight penetration increase in accordance to window aperture.

Boubekri et al (1991, 1993a) investigate subjects’ acceptability towards window size and sunlight penetration through office windows. During the field measurement, four windows with window to wall ratio (WWR) of, 10%, 20%, 40% and 60% were tested. Their findings indicate that WWR did not significantly affect the occupants’ emotional state or degree of satisfaction but sunlight penetration significantly affected their feeling of relaxation. Size of sunlit areas should not exceed 40%. In addition, office workers sitting near window prefer sunlight sparkles than large floods. They added that window may be more effective if it is placed next to student’s desk by allowing him / her to relax after focusing on a task. On the contrary, Dahlan (2006) found that library users that were sitting at 2m distance from a large window (i.e.: WWR of 80%) complained that the daylighting in the reading area was
too bright (i.e.: above 10% daylight factor). This indicates that window size has an affect on users’ visual comfort.

To further enhance the importance of windows in a workplace, Boubekri and Haghighat (1993b) conduct post occupancy evaluations for office building on workers that were sitting near or farther from a window. The importance of window was much greater for workers without window immediately adjacent to their workstation.

Stone (1998) survey 120 college-aged student subjects that are randomly selected and asked to do three types of tasks, namely filling, computational and creative tasks in windowless and windowed rooms. Each subject had 40 minutes to complete the task. After the 40 minutes was up, a questionnaire was administered to them. Findings revealed that windows do not affect subjects’ performance on their task. Statistically, there are no significant differences between responses from subjects in either room. It is interesting to know occupants’ responses for this particular investigation when exposed to a longer survey period. Therefore, in this study the decision was made to identify occupant’s response throughout a 6 month stay (in a hostel room) rather than just within a short specific time.

Shahnavaz as quoted by Veitch (2001) indicated that the illuminance preferred for offices with visual display unit (VDU) were lower compared to paper-based or horizontal tasks. Visually demanding tasks like reading and studying have higher preferred illumination levels as rated on a relative scale (abstract scale) than tasks that are intimate or more relaxed (e.g.: having conversation, browsing for books and etc.).
Shin and Huang (2001) agree to this argument emphasizing that east and west facing facades of high-rise buildings in Taipei have higher reflection glare compared to south and north facing facades. 74.4% of the subjects preferred daylight than artificial lights while working at the computer workstation. Moreover, 93.5% agreed that window availability in office is important. 51.8% of the participated computer workers also had their computer screens placed at approximately 90° to the window or to the side of the window, supposedly the most comfortable arrangement recommended in design guidelines for computer office environments (CIBSE 1996).

Sutter et al. (2006) conducted surveys on 8 workers in 8 different individual offices facing south-east in a building in the city of Vaulx-en-Velin, near Lyon in France. How the workers’ used their Venetian blinds over 30-weeks, periods were monitor. They found that workers have the tendency to lower and raise their blinds whenever external global illuminance was 15klx and 8klx, respectively. This action is because workers are believed to adjust their window luminance to below 1800cd/m² in order to avoid disability glare. In an investigation to correlate ambient indoor temperature with how workers controlled their shading system, Sutter et al found that more blinds are raised when the temperature is below 26°C inside the office. Nevertheless, when the temperature exceeds 26°C (observed during summer season), workers tend to tilt their blinds 10° downwards towards the ground. Foster and Oreszczyn (2001) also found that blinds are used to reduce glare on sunny days. They also added that smaller glazing areas in offices were more desirable by occupants due to lower solar heat gain.
In the case of naturally lit dwelling buildings, illumination levels may sometimes exceed the illumination level recorded in climate controlled buildings. Li et al (2006) simulate indoor daylight levels for interior areas in a high-rise residential flat in Hong Kong that faced large neighbouring building facing north, south, east and west were 800lx, 3000lx (both south and east) and 8000lx, respectively. Unfortunately, large amount of daylight, especially to interiors facing west, comes with large amount of direct sunlight causing glare problems, excessive brightness, and thermal discomfort (De La Flor 2005; Li 2006). Diffuse daylight obtained from mean daylight factor, showed that areas in flat at lower floor (1st floor) that were obstructed by other building initially received only 0.2 to 0.4% of daylight factor, which is less than standard maintenance illuminance during daytime period. The recommended daylight factors in dwellings are at least 1%, 1.5% and 2% for bedroom, living room and kitchen, respectively (CIBSE 1987). This CIBSE standard was based on European sky illuminance. In Malaysia, the sky illuminance is higher (i.e.: around 80,000 lux) thus making a lower daylight factor in Malaysia does not mean inadequate amount of daylighting required in its buildings.

3.3.2 Other effects of daylighting

An investigation by Shin and Huang (2001) in Taipei, found that reflection glare increases in relation with the outdoor temperature. In summer, with average outdoor temperature of 29.3°C in the morning and 31.5°C in the afternoon, 16 respondents were interview to examine their glare sensation while indoors. The findings suggested that higher temperature makes glare more noticeable to occupants. They added that the more occupants were exposed to reflection glare the lesser they feel visually comfortable.
Chauvel et al. (1982) conducted a laboratory investigation on how to reduce the effects of discomfort glare from windows. Twenty-five subjects were tested in two stages of experiment, pertaining subjects’ visual comfort towards various sizes of windows with: (1) unobstructed view and (2) windows with curtains. Windows are all north facing and made to observe real sky under overcast and clear skies but without the sun presence (from sky luminance of 1100 to 5000 cd/m²). Each subject was sitting facing a window, 2.5m away from it. Each test area is equipped with artificial lights close to these windows. Results from the first stage showed that subjects are less comfortable after seeing the windows with artificial lights switched on. In the second stage, artificial lights at the interior side of the window wall were switched on by a variable amount from 200 to 1500 lux, on a light grey wall, reflectance factor = 0.7.

The usage of curtain was believed to divide sky luminance by two resulting in a more pleasant interior surrounding when it is in used (Chauvel 1982). Statistically through Friedman tests, they enable to identify that subjects find that large window (area of 9m²) is more pleasant than smaller window (area of 3.7m²) with and without curtain usage. Smaller window with artificial light (100 cd/m² or more) is more pleasant than without. Their findings conclude that discomfort glare from single window (except for a rather small one) is practically independent of size and distance from an observer but is critically dependent on the sky luminance.

A psychological approach in the study of naturally lit spaces in libraries is conducted in three libraries, namely, Middleton library, Darwin College Study Center
and Jesus College Library, Cambridge by Parpairi, et al (Parpairi 2000; Parpairi 2002) which focused on the users' preference regarding their visual comfort concluded that users sitting at location points without the reach of daylight are likely to feel unmotivated and visually uncomfortable. However, users sitting at naturally lit areas are happier and motivated to do their studies. Similar effects of daylighting also affected younger school children in their studies. A report by Mahone – Heschong Group (Mahone-Heschong 1999) show that children in classroom with skylights are more energetic, happier and perform better in class than children in ordinary classrooms. More over, children in day lighted classrooms obtain higher grades for Math examinations. Teachers verified these aspects and added that they also felt calmer due to tolerable responds from their students.

Veitch (2001) found that the nature of setting determined window preference for university students. Results from the users’ preference survey show that the users prefer no windows at lecture halls, public washrooms, and computer workrooms, whereas large windows are insisted upon in family rooms, dormitory bedrooms, and libraries. Office workers and schoolchildren also preferred to work and study at spaces with windows. Optimal window size for offices appears to be in the range of 1.8 to 2.4m in height and somewhat wider than taller, in order to provide for wide lateral view (Galasiu and Veitch 2006). Furthermore Veitch (2001) concludes that users have specific preference towards the naturally lit spaces leading to desired quantify of artificial lighting depending on type of task and distance from window (Galasiu and Veitch 2006). Spaces with lesser visually critical tasks and prolonged occupying hours such as library are suggested to be naturally lit. However, spaces with video display terminal and lecture halls are required to have no day lighting.
implementation. This is due to the fact that daylighting has been associated with improved mood, enhanced morale, lower fatigue and reduced eyestrain which made it suitable to be utilised for long task performance (Edwards 2002).

Matusiak (2006) has come up with suggestions on the impact of window forms on size and depth impression of a room. The investigation was carried out at Norwegian University of Science and Technology, Norway. Twenty-two subjects in various age groups took part in test room with dimension of 2.5m (w) x 4.2m (l) x 2.5m (h) carried out in midwinter (24 January 2004) around noon (11:00 to 13:00 p.m.) under overcast sky. Findings through subjects votes on their impressions of room size based on three main window forms, namely, vertical narrow, horizontal narrow and many small window forms are collected but not explained through statistical manner. In general, vertical narrow window make the room appears as higher while horizontal makes it wider. Many small windows placed in the window wall make the room to appear larger than if composed of larger size windows. In the test room with a window situated exactly at the middle of the wall and had an equal to half of the wall area; resulted in making the room seems to be deeper than usual.

**Summary of Review**

In sum, it can be revealed that visual comfort through daylighting via the side-lit windows are partially responsible for indoor illumination and glare discomfort. Furthermore, it can be assumed that:

1. **Daylighting through side-lit windows provide sufficient daylight transmittance, provided that the window is design according to the optimum window to wall ratio appropriate to the particular indoor space.**
2. Window orientation and other means of shading such as, usage of blinds, curtains, and overhangs reduce the amount of glare that is perceived to be the cause of visual discomfort and excessive heat gain by occupants.

3. Outdoor condition such as weather and external illumination determine the daylight availability and occupants’ visual comfort.

4. Occupants have innate visual expectations toward their indoor surrounding.

5. Occupants’ visual discomfort is not influenced by the window size.

3.4 Acoustics comfort based on indoor environmental noise condition

The importance of acoustic comfort investigation is not only depending on objective measurement alone. Subjective measurement should be incorporated as well. Zannin et al. (2003) in their acoustic comfort investigation in Brazil suggested that despite reduction on the urban noise pollution recorded trough objective measurement, subjective findings show an increase on the perception of the urban noise, mainly the noise generated from neighbourhood of the interviewed occupants.

In the UK, Skinner and Grimwood (2005) undertook a survey of environmental noise levels collected 24-hour noise measurement from 1160 sample dwellings and over 5500 questionnaire responses from the adult population from 1990 until 2000. They found that in the last ten years, there has been increase in the proportion of people reporting being annoyed by noise from neighbours and road traffic. Similar sound pressure level increase was also detected from their 16 hour (day-time) and 8 hour (night time) equivalent noise level indicators, namely $L_{Aeq(16)}$ and $L_{Aeq(8)}$, respectively.
In another subjective measurement conducted on occupants in houses exposed to road traffic noise has been done by Klæboe and co-workers (2004). 3947 occupants in Norway were asked whether they felt annoyed with the traffic noise when they are indoors and outdoors. The responses found suggest that occupants were more annoyed indoors than outdoors especially the ones with inferior window quality.

In terms of dwelling condition, occupants in crowded interior spaces often complained of noisy conditions and lack of privacy. If not treated, this condition will bring to stress. Winchip et al. (1989) found that parents living in a large household concise of at least one child experienced more stress than those without children. Miedema and Vos (1999) found that noise annoyance is not related to gender but has an effect on age. Their data is collected from investigations of noise exposure from aircraft, road traffic and railway in Europe, North America and Australia. When exposed to similar noise exposure level, relatively young and relatively old persons are less annoyed than persons with ages in between. This is due to deterioration of hearing sense in relatively old persons and is not related to environmental noise condition.

In Germany, Kuerer (1997) suggest that acoustic comfort is connected to building insulation design. Based on the Classes of Acoustical Comfort in Housing proposed by the European Commission, the acoustic comfort for occupants in several types of dwelling typology is investigated by the means of their indoor sound propagation. Indoor sounds are concise of speech, footsteps, sanitary noise and recreational noise. Most of occupants are satisfied with the standard acoustic quality is Class II, where occupants usually find quietness and rest in their homes. But if further
improvement is needed, additional costs of 0.3% are required to build houses to meet the Class III acoustic quality, which can also reduce outdoor noise. In the city of Curitiba, Brazil, Zannin et al. (2002) reveal that occupants in residential areas suffer from noise pollution above 65 dBA mainly cause by traffic noise. They also added that acceptable noise level in residential areas should be less than 62 dBA as recommended from US Department of Housing and Urban Development.

Summary of Review

In sum, both objective and subjective measurement in acoustic comfort examinations are important. Based on the limited works been done and presented in this review, the following assumptions are made:

1. Occupants are annoyed with traffic noise when they are indoors.

2. Occupants in typical homes with standard sound insulation are at ease with indoor sounds such as; speech, footsteps, sanitary noise and recreational noise.

3. Most noise investigations for indoor spaces are measured in terms of A-weighted sound levels, as in many references. This action is also adapted in this study.
3.5 Investigations of integrating indoor comfort factors

The physical indoor environment includes: indoor air temperature, air flow, relative humidity, mean radiant temperature, illumination, discomfort glare, noise annoyance, indoor air quality, vibration, electromagnetic and electrostatic environment. However, not all physical environments of indoor comfort are equally important to the occupants. Researchers usually analysed either the top four or adding other distinguish type of comfort into their system to suit contextual comfort needs (Gonzalez 1997; Chiang 2001; Chiang and Lai 2002; Kim 2005; Mahdavi and Unzeitig 2005; Chau 2006).

Occupants' comfort can be identified through perceptive-cognitive aspects towards a building that subsequently lead to affective responses like satisfied or dissatisfied, hot or cold, annoyed or not annoyed, etc. Gonzalez et al. (1997) and Haghighat and Donnini (1999) investigated the users' satisfaction through multiple indoor environment conditions in their workplace using semantic differential (Osgood 1957) questionnaires. Their office workers' evaluation was focussed on conditions, namely, satisfaction, aesthetic evaluation, indoor air temperature, noise, air quality and spaciousness. Illumination was not included in their users' evaluation because it was suggested that workers were not the best judges of their lighting conditions. However this argument was not supported by most researchers in daylighting and other lighting researchers. A review of workers' preference and satisfaction with their office luminous environment by Galasiu and Veitch (2006), stressed that workers showed strong preference to daylight in workplaces as they associate it with better health. Better office illumination also ensures higher workers' productivity (Boyce 1981).
Thermal indoor condition is also often associated with acoustics investigations (Miedema 2005; Nagano and Horikoshi 2005; Kruger and Trombeta Zannin 2007). In relation between the outdoor temperature and indoor environmental noise collected in the Netherlands during a 3 months period, showed that increasing outdoor temperature was consistently associated with increased in noise annoyance. 15°C differences in temperature (from 7.9 to 22.7°C) was estimated to produce a change in annoyance that was equivalent to that produced by a 1 to 3 dB increase in noise exposure (Miedema 2005). It was also suggested by Miedema et al (ditto) that noise annoyance is greater in warmer seasons. In agreement with Miedema et al (ditto), Nagano and Horikoshi (2005) found that operative temperature show slight increase on auditory comfort sensation votes. The underlying reason for the increase in annoyance in association with the increase of temperature is perhaps due to the fact that the occupants were exposed to more external noise as a result of opening their windows, especially during summer season.

Despite providing acceptable heat gains and losses performances, Krüger et al. (2007) showed that building envelope materials consisted of timber and expanding polystyrene show poor acoustics performance. They stressed that the performance of a house should not be only based on its thermal performance but also its acoustics performance as well, hence proving that combined indoor environmental and comfort factors conditions are important to occupants’ satisfaction.

Meanwhile Chiang (2001) assessed indoor comfort factors that were closely related with international standards, namely, air quality, air velocity, relative humidity, air temperature, acoustic, and illumination. In their findings, occupants in
the elderly care centres in Taiwan voted indoor air quality as the most influential physical environment for comfort, followed by air velocity, illumination, air temperature, relative humidity and lastly noise level. Lower annoyance found for older person may also be caused by deterioration of the hearing sense which also agreed with the findings revealed by Miedema and Vos (1999). Another investigation of multiple indoor comfort factors (Mui 2008) showed that, 440 occupants from elderly care centres in Hong Kong were satisfied with the current overall environmental conditions of the elderly centres at typical indoor environmental conditions, attributed by operative temperatures of 25.4 ± 3°C, carbon dioxide concentrations of 970 ± 460 ppm, illumination levels of 490 ± 460 lux and equivalent sound pressure levels of 69 ± 8 dBA.

Relationship between objective and subjective indicators of indoor comfort indicate subjective sensor ratings were significantly better than objective indicator at predicting overall rated indoor comfort. In an investigation on hospital patients and staff influence toward their temperature, relative humidity, noise and illuminance level in Sweden, Fransson et al. (2007) suggested that it is difficult for people to isolate one sensory experience from another and also, that people sometimes are not aware of what influences their overall reaction. Another indoor environment satisfaction rank investigation in 26 offices in five European countries that consisted of five factors, namely, warmth, air movement, humidity, light and noise. Warmth and air movement were more important than satisfaction with the level of lighting or humidity (Humphreys 2005). However, Humphreys (ditto) stressed that combined indoor environment indices is subjected to cultural and historical variation and not completely constrained by human physiology.
Chiang and Lai (2002) added three more comfort factors which are greens, vibration and water quality in their study on indoor environment health in Taiwan into the original six physical environments by CIBSE (CIBSE 2006a). By applying the Analytical Hierarchy Process (Saaty 1985) to rank all nine of the comfort factors, they found that the latter indicators (greens, vibration and water quality) were not significant according to built environment experts' votes. These experts suggested that, respectively, indoor air quality, thermal comfort, acoustics, illumination and electromagnetic and electrostatic environment are influential to occupants' health in Taiwan. Zhao and Jones (2007) have devised a ranking system that assessed the potential of the site with the design proposition for natural ventilation in non-residential buildings in terms of wind, temperature, humidity, noise and pollution conditions. After applying constraints and alternatives to the ranking systems, the particular building's performance is assessed according to their energy saving, thermal comfort, acoustics control, indoor air quality performances and cost. However, their literature concentrate on the framework development of the systems and no result was provided.

In another indoor comfort factor ranking study, indoor air quality was also considered the most important environment attribute in high-rise residential estates of Hong Kong followed by indoor noise; water consumption; energy consumption; landscaping and usage of recycle materials, respectively (Chau 2006). However, the result was perhaps due to public concern regarding the wide speared SAR epidemic in 2004, which could encourage Chau (ditto) to neglect occupants' illumination satisfaction assessment. But in reality, many occupants living in high-rise residential
estates complained that not enough daylight was evidence in their apartment especially the kitchen area (Ng 2003; Lau 2006).

Laurentin et al (2000) confirmed the hypothesis that indoor temperature can affect occupants’ visual comfort. 12 male and 8 female college-aged subjects participated in their controlled visual comfort survey. Subjects were exposed to two temperatures, namely at 21°C and 27°C under 3 light source types, i.e.: daylight, artificial lights, and combined lighting, at a constant illumination of 300 lx. They revealed that female subjects felt unpleasant when the air temperature was at 21°C compared to male subjects. Female subjects also perceived the light environment during that particular temperature as unpleasant. Laurentin et al (2000) suggested that the difference behaviour between male and female subjects concerning thermal and visual condition was not influence to gender differences but rather to the air temperature of 21°C not being acceptable to female subjects. Furthermore, it seems that when the thermal condition is rejected, the lighting condition is also rejected. Thus, suggesting that the thermal comfort parameter was influenced by air temperature in this case more than by visual comfort.

Summary of Review

Literatures reviewed under this particular heading is summarised as below:

1. Not all physical environments of indoor comfort are equally important to the occupants. Selection of these indoor comfort environments in predicting occupants' overall comfort perception is justified to suit contextual comfort needs.
2. Occupants perceived their indoor environment differently depending on their age, immediate surroundings (i.e.: outdoor and indoor environments) and expectations (i.e.: different expectation lead to different tolerant level).

3. Increase of indoor temperature show slightly more auditory and visual discomfort complaints.

4. Cultural contexts, warmth and air movement are considered to be more important than level of lighting and humidity.

Summary of Chapter

Observation from the literatures showed that many investigations regarding indoor conditions were either conducted only through objective measurement or subjective measurement. The few studies that compared findings from both measurements showed contradicting findings, which resulted from occupants’ acclimatisation strategies, such as, switching on the fan, usage of window curtain or blinds, and wearing clothes based on the weather condition. For instance, there were findings suggesting that people can tolerate rather warm indoor conditions (Abdul Rahman and Kannan 1996; Baker and Standeven 1996; Kwok 1998; Feriadi and Wong 2004; Sh.Ahmad 2005; Dahlan 2008). Research has also shown no significant deterioration of working performance when sitting in a windowless room (Stone 1998; Veitch 2001). There is also evidence that people still show annoyance to noise despite the reduction of noise level throughout a number of years (Zannin 2003). Therefore, any studies of indoor comfort in relation to how Malaysian student occupants perceive their indoor conditions should include thermal, visual and acoustic conditions’ physical measurements.
Moreover, in order to tackle specific design problems, it has been suggested in several other works (Chiang 2001; Chiang and Lai 2002; Humphreys 2005; Chau 2006) that prioritisation of indoor comfort perception may be a suitable solution in designing for a more sustainable building design, through understanding occupants’ indoor comfort perception assessments. Reviewed works also suggest that their response, either through individual or integrated indoor comfort perception surveys, serves as an effective instrument to assess a building’s comfort performance.
CHAPTER 4

RESEARCH METHODOLOGIES

4.1 Introduction

The aim of this chapter is as follows:

i. To review the conceptual framework of this research.
ii. To review objective methodologies used in assessing indoor climates.
iii. To review subjective methodologies used in assessing occupants’ indoor comfort perceptions.
iv. To describe the case study selected in this research.

4.2 Conceptual framework of the research

Indoor climate that includes thermal, visual and acoustics conditions in building in hot-humid climate has different control solutions than their counterparts in cold-wet and hot-arid areas. Natural cooling can occur only when there is vigorous air motion through evaporative cooling method. Shading strategy here is more important compared to hot-dry climate areas because very humid areas are often very overcast thus increases the diffuse-beam radiation. The large solar radiation input makes it crucial to provide shade from the complete sky and not just the solar disc to avoid heat gain and glare. Openings are oriented to make use of local breeze and prevailing winds. Indigenous houses here were built on stilts to take advantage of the natural increase of wind speed with height (Oke 1978). Unfortunately, modern buildings have
deep floor areas and built with fast and cheap construction materials without considering gain heat problems. Noise from near by traffic also causes discomfort indoor, especially when the windows are opened. Schematic depiction of fluxes involved in the indoor comfort of a single story building is shown in Figure 4.1. This figure shows that, when the windows are opened, in order to promote air movement, heat and noise can enter and cause discomfort (-). Moreover, windows are not obstructed, thus guarantying daylighting, which promotes comfort (+).

Figure 4.1: Schematic depiction of fluxes involved in the indoor comfort of a single storey building.

(Note: Yellow shading represents the daylight patch that occurs in a room. Meanwhile, blue shading indicates the surfaces that do not have any daylight patch.)

Figure 4.2 shows schematic depiction of fluxes available around typical multi-storey Malaysian hostels. Similar principles drawn in Figure 4.1, namely, sunlight and daylight exposure, prevailing wind, and traffic noise are repeated. The interaction between the outdoor and indoor condition is depicted through two types of façade designs. This first façade design is depicted to have long roof overhang, balconies at
every floor, adequate distance from the nearby highway and sound barrier installation. These designs features are associated with low heat gain, shaded indoor areas but with adequate daylighting, and decrease noise annoyance mainly from vehicles which are considered comfortable to occupants. On the other hand, the second façade design is depicted to have no long overhangs, no balconies, closer distance with the near-by highway and no sound barrier installed.

In order to distinguish the limit between the analysed systems with other system components, a system boundary is established. In Figure 4.2, the system boundary is indicated using bold long dotted line around the multi-storey hostel’s immediate surrounding.
Figure 4.2: Comparison of good and bad hostel's building envelope designs with heat, daylight and sound from their immediate surrounding.
The idea emphasised in this research was to assess indoor comfort perception in typical multi-storey hostels in Malaysia. The indoor comfort perception assessment consists of two components namely, first, identifying the influences of physical indoor factors and second, identifying the influences of occupants' comfort perception in typical multi-storey hostels. Relationships between these components were divided into six levels, i.e.: focus, predominant indoor comfort factors, indicators, external condition influences, daytime period and architectural influences.

Figure 4.3 shows the hierarchy of influences on physical indoor factors in selected hostels. The 'focus' of the relationship was identified in the first level of the hierarchy. The second level, that is the 'predominant indoor comfort factors' consisted of thermal, visual and acoustics. The following level show 'indicators' that were used to measure the indoor comfort factors, namely, operative temperature, daylight ratio and sound pressure level for thermal, visual and acoustics, respectively. These indicators were assumed to be influenced by three sets of factors, which were represented by 'external conditions' in level four, 'daytime period' in level five and 'architectural influences' in level six.

External conditions (level four) were emphasised by microclimate conditions of the case study sites. Most of the data collected for this level was obtained from the meteorology station or measured in open fields to identify local sky condition and illumination. Three periods during the measurement were highlighted, namely, morning, afternoon and evening for visual and acoustics, but for thermal, night time was added. The final level, architectural influences, consisted of floor levels, orientations, shading devices and window opening dimension.
The three latter levels have different characteristics. The external condition influences are considered dynamic indicating that weather is uncontrollable and can be wrongly forecast. Daytime periods are considered rhythmic and changes according to time. Meanwhile, architectural influences are considered fix or unaltered except if the particular building case study is obstructed by other buildings or any other major infrastructures like high-ways being built.

![Figure 4.3: Hierarchy of influences on physical indoor factors in typical hostels in Malaysia.](image)

Figure 4.4 illustrates the relationship between occupants’ indoor comfort perception with their surrounding physical influences. Modifications that give a more straightforward indication of factors in each level were made to aid occupants. The three predominant indoor comfort factors still remain the same. In measuring occupants’ indoor comfort, questionnaires using semantic differential scales to assess thermal, visual and acoustics comfort were administered. Data collected from occupants was in the form of comfort votes and additional clothing insulation (clo...
value) information for thermal comfort assessment only. External condition influences in this particular organisation was simplified to rainy and clear day conditions. Daytime period remain the same, meanwhile the architectural influences only focused on window function.

![Diagram](figure4.4)

Figure 4.4: Hierarchy of influences on occupants’ indoor comfort in typical hostels in Malaysia.

The relationship among all three inputs, namely, thermal, visual and acoustics conditions which were influenced by objective, subjective, architectural and daytime periods were analysed based on their indoor climate condition. The output of the indoor climate condition through the overall relationship was suggested to subsequently address the indoor climate condition in typical multi-storey hostel that was acceptable to occupants. Conceptual framework of the whole interaction as a system is shown in Figure 4.5.
Research Methodologies

After explaining the conceptual framework, this chapter moves to its second and third aims, namely, reviewing objective and subjective methodologies.
4.3 Preliminary work

A pilot study has been conducted prior to the actual field measurement. The objectives were: (1) to determine the appropriate measurement spot and duration; (2) to provide the author hands on experience with the instruments; and (3) to test the draft questionnaire form. The pilot study, which took place from March 12 until 19, 2007, was carried out in University Hall, Cardiff University, Cardiff. This 10 storey tower was chosen because it is the highest hostel in Cardiff. Six subjects participated in the survey in order to test the questionnaires developed for field use. Draft questionnaire forms were sent online to students occupying hostels in Malaysia and other student volunteers in Cardiff University.

In general, the pilot study served its purpose as an exercise to familiarise with objective and subjective measurements procedures before conducting the actual field measurement in Malaysia. Several amendments have been undertaken. The revised procedures are described as follow:

i. Instead of measuring one room per-day, three rooms located at different vertical room locations, namely, at low, middle and top floors were measured simultaneously.

ii. The previous airspeed meter (AIRFLOW propeller meter) was replaced with an AIRFLOW anemometer that provides a more precise reading than the former one.

iii. Thermal sensors and lux meter were placed at 2m distance from the window wall to avoid direct contact with sunlight. This location also represents the centre of the measured room.
iv. In terms of subjective measurement, the terminology used in describing glare discomfort was simplified by asking subjects regarding their usage of window curtain and artificial lighting during Clear Day.

4.4 Instruments: Sensors used

1000 Series Squirrel data logger together with Darca Windows software was used (Plate 4.1). Sensors connected to Eltek were consisted of: air temperature and relative humidity probe and globe thermometer. This data logger was opted due to its highly accuracy: ±(0.1% of reading, +0.2% of range span), rapid memory download at 38400 baud, up to 99 logging "runs" storage space and can be operated using six 1.5V batteries. The data logger was stationed on a chair 2.0m from the window wall with equal length from the left and right interior walls of the measured rooms.

There were three sensors used to measure the indoor thermal conditions. The temperature and relative humidity probe is shown in Plate 4.2. This probe is 260mm in length and 25mm in diameter. The humidity sensor is a solid-state device which changes its electrical characteristics in response to extremely small changes in humidity. Meanwhile, the temperature sensing system also uses integrated circuit technology. Globe thermometer is measured as the internal temperature of a hollow sphere (painted in black) exposed to environment (Plate 4.3). The temperature recorded is then translated into operative temperature which is similar to occupant’s body temperature. Air speed in the measured room was measured using a hotwire thermo-anemometer from AIRFLOW (Plate 4.4). Only the anemometer was used during the measurement period.
Illumination and luminance were measured using ISO-TECH lux meter (Plate 4.5) and HAGNER universal photometer (Plate 4.6), respectively. Both light measure instrument was powered by one 9V battery each. Images of the sky during measurement period and view of rooms were captured using Nikon CoolPix 990 fitted with Fish eye lens (Plate 4.7). For noise measurement, DAWE digital impulse sound pressure level meter was used (Plate 4.8). This instrument is equipped with a permanent attached quarter inch diameter pre-polarised electret (typically 10mV/Pa) microphone. The digital sound pressure level is also suitable for free field and random incident sound measurement. It is powered using four 1.5V batteries.
4.4.1 Objective measurement procedures

Three rooms at different locations, namely, at the lowest, middle and top floor for each available room orientation are simultaneously measured for six days. After the six days duration ended, another set of rooms will be selected at another room orientation. Prior to the objective measurement, five specifications namely, the room’s dimension, shading ratio, window to wall ratio (WWR), openable window to wall ratio (OWWR) and surface reflectance factor were identified before starting the measurement. Descriptions regarding these specifications will be given in heading 4.8.

Subsequent to the objective measurements, questionnaire survey was conducted in the same case study hostels, which was still in the month of July. The decision not to collect the questionnaire at the same time as the objective measurements was due to the lack of manpower in order to execute multiple tasks at the same time. Furthermore, the author was advised by the hostel managements to set up the measured rooms during university semester break (i.e.: from the first week of May until the first week of July) to avoid instruments from been damaged or moved by the student occupants. The periods for the measurement and survey were in the same month and so the weather condition should be similar. The survey questions also asked general questions regarding occupants’ perception throughout their stay in the particular hostels and not fixed to a precise time of survey.

4.4.1.1 Determining weather type (i.e.: either Rainy or Clear Days)

In this study, the case studies were selected at locations with high ratio amount of sky visible or sky view factor (SVF) when captured using Nikon CoolPix 950 digital camera fitted with a Nikon FC-E8 fisheye lens (Plate 4.7). SVF at the
particular locations were observed to be between the ranges of 0.9 to 1.0, where, the value ‘1’ shows no foliage or obstruction visible in the photograph (Oke 1978; Grimmond 2001; Svensson 2004; Chapman 2007).

In order to identify the relationship between outdoor and indoor microclimate, the weather condition and cloud patterns determined by fisheye images of the case study locations were monitored. Cloud patterns were monitored four times a day, namely at 8:00 a.m., 12:00 p.m., 3:00 p.m., and 5:00 p.m. based on sky condition images captured. Images are enclosed in the appendix. ‘Rainy Day’ was determined based on heavy overcast sky with signs of precipitations, while ‘Clear Day’ was determined based on clear sky with none to very little cloud distribution.

4.4.1.2 Indoor thermal objective measurement procedures

Thermal measurement started from May 12 until July 6, 2007. Total measurement days were 6 days per-orientation for 24 hour period. The first three days were dedicated to monitor indoor thermal conditions with fan switched off. The following three days were used to monitor indoor thermal conditions with fan switched on. Procedures for indoor thermal condition with and with out fan are explained as follow:

A) Hourly monitoring of indoor thermal condition without fan

Indoor thermal investigations consist of air temperature, relative humidity, operative temperature and air flow investigations. Three of the sensors except for air flow instrument are connected to the data logger. Measurement was conducted from
first day until the third day per-orientation. The procedures for indoor thermal measurement are as follows:

1) Ceiling fan was not switched on during this measurement.
2) Windows were left open throughout the measurement period.
3) Reading logged using the Eltek Data Logger (Plate 4.1) was set to take average readings within ten minutes.
4) Three sensors, namely air temperature, relative humidity and globe thermometer sensors (Plates 4.2 and 4.3) were stationed 2.0m from the window in order to monitor the temperatures collected in the centre of the measured rooms. Arrangement of these sensor and Eltek Data Logger is shown in Plate 4.9.
5) The air speed meter was hand held at the middle of the window’s opening (Plate 4.10). Readings were recorded hourly.

B) Hourly monitoring of indoor thermal condition with fan
1) Procedures A.2 to A.4 were repeated on the following day with fans switched on, namely, the fourth day until sixth day per-orientation.
2) Air speed reading was taken 2.0m distance from that particular window and mounted 1.0m from the floor. The location of the measurement distance changed because during this particular condition, the predominant airflow source came from the ceiling fan and not from the outside.
4.4.1.3 Daylighting measurement procedure

Daylighting measurement started in May 12 until July 3, 2007. Each room orientation was measured for three days at three different vertical room locations. Measurement for both external and internal illuminations started from 8:00 a.m. to 5:00 p.m. Indoor visual investigation is divided into two types; namely, the daylight illumination and glare investigations. The procedures for both of these investigations are as follow:

1) Two ISO TECH lux meters (Plate 4.5) were used in this investigation, namely, for external and internal purposes.

2) Readings were taken six times per hour. The mean value recorded were used as a constant value for a particular hour.
3) Internal illumination measurement interval between one measured room to another was 15 minutes. This interval was decided to provide the author with ample time to record the measurements in measured rooms at three different floor levels.

4) For indoor measurement, the lux meter was located 2.0m distance from window and mounted 0.8m above the floor on a tripod. The reason for this was to obtain the lux reading for the centre of the measured room. Furthermore, mounting the lux meter 0.8 above the floor enables the author to collect daylight at desk top level. Windows were left exposed with no curtain.

5) In order to record the interior design features of a measured room, 180° view of the room was captured using a fisheye lens camera.

6) Simultaneously the second lux meter was mounted 1.5m from the ground on a tripod in the middle of an open field close to the case study building (Plate 4.11). Readings were also taken six times per hour similarly to procedure (2).

7) Glare measurements were taken horizontally using Hagner photometer (Plate 4.6) 2.0m from the window and 1.0m from the floor. The author looked through the telescope (that is incorporated with the Hagner photometer) and points it to the window in the measure room (Boyes 2002).

8) The field of view for the Hagner photometer was 40° in altitude and 90 ° in azimuth so that it would be measuring the mean luminance in a horizontal 40 ° band (Loe 2000) (Figure 4.6). This particular band was suggested as suitable in determining occupant’s visual lightness and interest.

9) Readings for luminance measurement were also recorded six times per hour with 15 minutes interval between the vertical room locations. Similar to procedure (3), this interval allowed the author ample time to record measurements in the measured rooms.
4.4.1.4 Sound pressure level measurement procedure

Three different room locations were chosen to measure the A-weighted sound pressure level differences at lower, middle, and top level of a hostel. Measurement started on the May 12 and ended on July 3. Selected case study hostels were located in free fields. The procedures for this measurement are as follow:
1) Sound pressure level measurements were taken using Dawe dB sound pressure level meter. Sound pressure readings were recorded continuously starting from 8:00 a.m. until 5:00 p.m. (9-hour period) for three days. Each measurement period lasted for 3 days per-orientation.

2) The sound pressure level meter was positioned 0.8m above the floor. Its quarter-inch diameter electret microphone was pointed outward through an opened window next to a study desk. The major noise source in these case studies was assumed to propagate from near by highways located in each site.

3) Similar to the objective visual measurement, sound pressure levels in the three rooms were recorded 15 minutes apart hourly. In this procedure, the representation of the 1 hour measurement time period used $L_{Aeq(1)}$. This particular representation has also been applied in other investigations in sound level measurements (Cowan 1994; Hossam El Dien and Woloszyn 2004; Skinner and Grimwood 2005).

4.5 Subjective Measurement of Occupants’ Indoor Comfort Perception

Subjective measurement was conducted using questionnaire survey. The survey was typically aimed to check whether the occupants in a particular building are contented with it and to identify any troublesome areas for further investigation. It also provides faster and easier comfort votes than to measure the thermal, visual or acoustics environment associated with the votes. Around 10 to 15 minutes was estimated for subjects to fill in the questionnaire.
4.5.1 Instrument: Questionnaire survey

In this study, the questionnaire is developed to suit the goal of this research. To aid subjects, the questionnaire was prepared in Bahasa Malaysia referring to a glossary of comfort terminologies. Terminologies used in the questionnaire were translated into Bahasa Malaysia according to the Kamus Dwibahasa: Bahasa Inggeris-Bahasa Malaysia (Bilingual Dictionary: English-Bahasa Malaysia) (Dewan.Bahasa.dan.Pustaka 1989).

Subjects’ comfort perception and satisfaction with the room in the hostels were measured via six-section questionnaire form, i.e.: Section A: Personal Detail; Section B: Thermal comfort rating; Section C: Illumination rating; Section D: Glare sensation rating; Section E: Noise rating and Section F: Participant’s opinion. Questions from section B to F were based on their indoor experience for a minimum of six months stay. Questions in those sections were arranged in pairs asking to rate comfort for rainy and clear day with one additional question asking subjects to rate their comfort at three specific time of the day, namely, morning (8:00 to 11:59am); afternoon (12:00 to 4:29pm) and evening (4:30 to 6:30pm).

The analyses for the survey was divided into two components, namely, Component 1 (i.e.: Section B to E) and Component 2 (i.e.: Section F). Component 1 was dedicated in identifying occupants’ comfort perceptions based on individual thermal, visual and acoustics conditions. Whereas Component 2 asked them to rank those individual indoor conditions in order to which of those conditions influence their overall satisfaction the most and vice-versa. An overall indoor comfort satisfaction vote was also asked in the end of this component.
4.5.2 Subjective measurement procedure

1) Questionnaires are distributed to subjects occupying the measured hostels.

2) Subject’s room location and window orientation were recorded in the ‘office use’ box of the questionnaire along with the wall, ceiling and floor reflectance factor.

In total there are 47 questions in the questionnaire form. Summary of each section is shown as follows:

1) **Section A:** Personal Details (7 questions): in this sections, subjects were asked for their age, degree, length of stay, activities and daily clothing wear. Six age groups were provided, namely, 20 and below; 21 to 25; 26 to 30; 31 to 35; 36 to 40 and 41 and above year old. Two degree types were given, namely undergraduate (i.e.: bachelor degree/ diploma) and post-graduate (i.e.: Masters Degree or PhD). Subjects’ length of stay was indicated using four lengths, namely, less than a year; a year; 2 years and 3 years and over. Five activities listed are shown in Table 4.1. Six types of daily wear clothing with different ranges of clo value were divided into twofold, namely during rainy day and clear day. Clo values were estimated from ISO7730 (ISO7730 2006). Table 4.2 shows the types of daily wear clothing typically worn by Malaysian female students.

<table>
<thead>
<tr>
<th>No.</th>
<th>Activity type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Studying</td>
</tr>
<tr>
<td>2</td>
<td>Socialising with mates</td>
</tr>
<tr>
<td>3</td>
<td>Relaxing in between classes</td>
</tr>
<tr>
<td>4</td>
<td>Just for sleeping</td>
</tr>
<tr>
<td>5</td>
<td>All the above</td>
</tr>
</tbody>
</table>
Table 4.2: Daily wear clothing

<table>
<thead>
<tr>
<th>Daily wear clothing</th>
<th>Clo value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1: Short sleeves t-shirt; track suit/jeans; underwear</td>
<td>0.5</td>
</tr>
<tr>
<td>Type 2: Long sleeves t-shirt; track suit/jeans; underwear</td>
<td>0.6</td>
</tr>
<tr>
<td>Type 3: Sleeveless t-shirt; sarong/shorts; underwear</td>
<td>0.3</td>
</tr>
<tr>
<td>Type 4: Short sleeves t-shirt; sarong/shorts; underwear</td>
<td>0.4</td>
</tr>
<tr>
<td>Type 5: Just sarong; underwear</td>
<td>0.2</td>
</tr>
<tr>
<td>Type 6: Sweater; cotton long sleeves shirt; track suit/jeans; underwear</td>
<td>1.0</td>
</tr>
</tbody>
</table>

2) **Section B**: Thermal Comfort Rating (17 questions): Subjects’ thermal comfort perception were according to 7-point Fanger scale ranging from ‘cold’ (-3) to ‘hot’ (3); ‘dry’ (-3) to ‘humid’ (3); and ‘draughty’ (-3) to ‘stuffy’ (3) (Fanger 1970). Table 4.3 shows the description of questions in Section B:

Table 4.3: Description of questions in Section B

<table>
<thead>
<tr>
<th>Code</th>
<th>Question</th>
<th>Scale type</th>
<th>Day condition/ time</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>What do you usually felt when you were in your room?</td>
<td>Thermal comfort</td>
<td>Rainy day</td>
</tr>
<tr>
<td></td>
<td></td>
<td>('cold' to 'hot')</td>
<td></td>
</tr>
<tr>
<td>B2</td>
<td>What do you usually felt when you were in your room?</td>
<td>Thermal comfort</td>
<td>Clear day</td>
</tr>
<tr>
<td></td>
<td></td>
<td>('cold' to 'hot')</td>
<td></td>
</tr>
<tr>
<td>B3</td>
<td>You feel that this room is...</td>
<td>Humidity</td>
<td>Rainy day</td>
</tr>
<tr>
<td></td>
<td></td>
<td>('dry' to 'humid')</td>
<td></td>
</tr>
<tr>
<td>B4</td>
<td>You feel that this room is...</td>
<td>Humidity</td>
<td>Clear day</td>
</tr>
<tr>
<td></td>
<td></td>
<td>('dry' to 'humid')</td>
<td></td>
</tr>
<tr>
<td>B5</td>
<td>When the window is opened, you feel...</td>
<td>Radiant</td>
<td>Rainy day</td>
</tr>
<tr>
<td></td>
<td></td>
<td>('cold' to 'hot')</td>
<td></td>
</tr>
<tr>
<td>B6</td>
<td>When the window is opened, you feel...</td>
<td>Radiant</td>
<td>Clear day</td>
</tr>
<tr>
<td></td>
<td></td>
<td>('cold' to 'hot')</td>
<td></td>
</tr>
<tr>
<td>B7</td>
<td>You feel that this room is...</td>
<td>Airflow</td>
<td>Rainy day</td>
</tr>
<tr>
<td></td>
<td></td>
<td>('draughty' to 'stuffy')</td>
<td></td>
</tr>
<tr>
<td>B8</td>
<td>You feel that this room is...</td>
<td>Airflow</td>
<td>Clear day</td>
</tr>
<tr>
<td></td>
<td></td>
<td>('draughty' to 'stuffy')</td>
<td></td>
</tr>
<tr>
<td>B9</td>
<td>Are you satisfied with the thermal condition of this room?</td>
<td>Overall</td>
<td>Rainy day</td>
</tr>
<tr>
<td></td>
<td></td>
<td>('dissatisfied' to 'satisfied')</td>
<td></td>
</tr>
<tr>
<td>B10</td>
<td>Are you satisfied with the thermal condition of this room?</td>
<td>Overall</td>
<td>Clear day</td>
</tr>
<tr>
<td></td>
<td></td>
<td>('dissatisfied to satisfied')</td>
<td></td>
</tr>
</tbody>
</table>
B11 How do you classify your thermal comfort during these hours (regardless of any weather condition)  

Thermal comfort  
- ('cold' to 'hot')  
- i) Morning  
- ii) Afternoon  
- iii) Evening

B12 Do you agree that the window size is alright for you?  

('disagree' to 'agree')  
None

B13 When the window is opened, is your room draughty?  

('never' to 'always')  
None

B14 Do you like the room to be airy?  

('Don’t prefer airy room' to 'prefer airy room')  
None

B15 When the window is opened, is your room humid?  

('never' to 'always')  
None

B16 Do you like the room to be humid?  

('Don’t prefer humid room' to 'prefer humid room')  
None

B17 Do you close the window on …  

('never' to 'always')  
Clear day

3) **Section C**: Illumination Rating (7 questions): Subjects’ were asked to rate their visual comfort via natural lighting using Hopkinson visual task scale, which ranges from ‘dark’ (-3) to ‘bright (3). Table 4.4 shows the description of questions in Section C:

<table>
<thead>
<tr>
<th>Code</th>
<th>Question</th>
<th>Scale type</th>
<th>Day condition/time</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>Describe your visual comfort in this room when only depending on natural lighting during.</td>
<td>('dark' to 'bright')</td>
<td>Rainy day</td>
</tr>
<tr>
<td>C2</td>
<td>Describe your visual comfort in this room when only depending on natural lighting during.</td>
<td>('dark' to 'bright')</td>
<td>Clear day</td>
</tr>
<tr>
<td>C3</td>
<td>Is natural lighting alone enough to light this room?</td>
<td>('inadequate' to 'adequate')</td>
<td>Rainy day</td>
</tr>
<tr>
<td>C4</td>
<td>Is natural lighting alone enough to light this room?</td>
<td>('inadequate' to 'adequate')</td>
<td>Clear day</td>
</tr>
<tr>
<td>C5</td>
<td>Are you satisfied with the natural lighting condition of this room?</td>
<td>Overall ('dissatisfied' to 'satisfied')</td>
<td>None</td>
</tr>
<tr>
<td>C6</td>
<td>Do you switch on the artificial lights during the daytime?</td>
<td>('never' to 'always')</td>
<td>Clear day</td>
</tr>
</tbody>
</table>
| C7   | How do you classify the room’s brightness during these hours (regardless of any weather condition): | ('dark' to 'bright') | i) Morning  
   ii) Afternoon  
   iii) Evening |
4) **Section D**: Glare Sensation Rating (6 questions): Discomfort glare was rated by Glare Sensation Vote that ranges from ‘not noticeable’ (-3) to ‘irritating’ (3). Table 4.5 shows the description of questions in Section D:

<table>
<thead>
<tr>
<th>Code</th>
<th>Question</th>
<th>Scale type</th>
<th>Day condition/ time</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>Do you agree that the window serves its purpose in allowing natural light into the room?</td>
<td>(‘disagree’ to ‘agree’)</td>
<td>None</td>
</tr>
<tr>
<td>D2</td>
<td>Do you experience glare sensation?</td>
<td>(‘never’ to ‘always’)</td>
<td>Rainy day</td>
</tr>
<tr>
<td>D3</td>
<td>Do you pull on the window curtains?</td>
<td>(‘never’ to ‘always’)</td>
<td>Clear days</td>
</tr>
<tr>
<td>D4</td>
<td>Do you experience glare sensation?</td>
<td>(‘never’ to ‘always’)</td>
<td>Clear day</td>
</tr>
<tr>
<td>D5</td>
<td>Are you satisfied with the overall glare condition of this room?</td>
<td>Overall</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(‘dissatisfied’ to ‘satisfied’)</td>
<td></td>
</tr>
<tr>
<td>D6</td>
<td>How do you classify your glare sensation during these hours (regardless of any weather condition)?</td>
<td>(‘Not noticeable’ to ‘irritating’)</td>
<td>i) Morning</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ii) Afternoon</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>iii) Evening</td>
</tr>
</tbody>
</table>

5) **Section E**: Noise Rating (7 questions): subjects were asked to rate their external noise annoyance using scale from ‘noisy’ (-3) to ‘quiet’ (3). Conditions were classified when the window was opened and closed. Table 4.6 shows the description of questions in Section E:
Table 4.6: Description of questions in Section E.

<table>
<thead>
<tr>
<th>Code</th>
<th>Question</th>
<th>Scale type</th>
<th>Day condition/ time</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>Do you find this room to be...</td>
<td>('Noisy' to 'quiet')</td>
<td>Rainy day</td>
</tr>
<tr>
<td>E2</td>
<td>Do you find this room to be...</td>
<td>('Noisy' to 'quiet')</td>
<td>Clear day</td>
</tr>
<tr>
<td>E3</td>
<td>Can you hear road traffic noise when the window in your room is opened?</td>
<td>('Never ' to 'always')</td>
<td>None</td>
</tr>
<tr>
<td>E4</td>
<td>Can you hear road traffic noise when the window in your room is closed?</td>
<td>('Never ' to 'always')</td>
<td>None</td>
</tr>
<tr>
<td>E5</td>
<td>If you can hear the road traffic noise, will it be annoying to you?</td>
<td>('Annoyed' to 'not annoyed')</td>
<td>None</td>
</tr>
<tr>
<td>E6</td>
<td>Are you annoyed with the external noise condition heard when you are</td>
<td>('Annoyed' to 'not annoyed')</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>in this room?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E7</td>
<td>How do you classify the exterior noise level heard from your room</td>
<td>('Annoyed' to 'not annoyed')</td>
<td>i) Morning</td>
</tr>
<tr>
<td></td>
<td>during these hours?</td>
<td></td>
<td>ii) Afternoon</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>iii) Evening</td>
</tr>
</tbody>
</table>

6) Section F: Subject’s Opinion (3 questions): All three questions in this section are open ended questions. Question F1 lets subjects to rank 7 comfort types accordingly in each empty box (refer to questionnaire form in appendix). Question F2 asked subjects to respond to a 7-point scale ranging from ‘dissatisfied’ (-3) to ‘satisfied’ (3) based on their overall comfort sensation while in their room. Question F3 provides written space for subjects to comment on their overall indoor environment. Table 4.7 shows the description of questions in Section F:

Table 4.7: Description of questions in Section F

<table>
<thead>
<tr>
<th>Code</th>
<th>Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>F.1</td>
<td>Which of these conditions most influenced your comfort sensation when you are in your room?</td>
</tr>
</tbody>
</table>

**Indoor conditions:** (1) Indoor Temperature; (2) Airy indoor condition; (3) Humid indoor condition; (4) Sunlight heat from window; (5) Adequate natural lighting; (6) Glare sensation from window; (7) External noise annoyance

F.2 What is your overall satisfaction rate for your room’s indoor comfort condition?

F.3 Do you have any recommendations to improve your room’s comfort condition?
4.6 Overall Indoor Comfort Perception Assessments

The overall indoor comfort perception was identified through occupants’ overall satisfaction vote. The overall satisfaction vote or the dependent variable (DV) was examined against two sets independent variables (IV), namely, architectural features and the indoor comfort perceptions. The first variable set consists of window size, shading ratio, vertical room location, and room orientation. The second variable set includes the three individual indoor comfort perceptions, namely, thermal, visual and acoustics comfort. The relationship between DV and IV was tested using multiple linear regressions in Statistical Package for Social Sciences (SPSS).

4.7 Statistical Analyses

4.7.1 Data processing and archival

Statistical Package for Social Sciences (SPSS) version 12.0 was used to analyse results in this study. SPSS is among the most comprehensive statistics package program for multivariate statistics (i.e.: multivariate analysis of variance (MANOVA) and multiple regression) compared to BMDP, SAS and SYSTAT programs. SPSS was chose for its ability to handle several versions of the same basic analysis on the same set of data. BMDP and SAS on the other hand are ideal to do preliminary tests for fast and interactive work. Meanwhile, SAS handles extensive data manipulation but its output is difficult to interpret than that of other packages unless the researcher is well verse in mathematical/ statistical training (Tabachnick 2007).

There are four types of statistical analyses applied in this research, namely through descriptive statistics, analysis of variance (ANOVA) with Two-tailed
Significant Test, Freidman Test and Multiple Linear Regression Model. Explanation on data interpretation of each statistical analysis and to which chapter they are applied are as follow:

i. **Descriptive Statistic**

This type of analysis consists of the mean and standard deviation or can also include maximum and minimum characteristics of the data set as well. ‘Mean’ is intended to express the average or typical value while the ‘standard deviation’ is a measure of the mean’s spread or dispersion. Descriptive statistics can come in many form of display, such as table, histogram superimposed with normal curve, bar chart and many more. It is used throughout Chapter 5, 6, and 7.

ii. **ANOVA repeated measures**

Analysis of variance (ANOVA) is an inferential statistics test used to determine whether an independent variable has had a statistically significant effect on a dependent variable. In a repeated measure, each case or subject is tested against every condition of the assessments. Information that can be delivered from this analysis is to locate more specifically the sources of systematic variation in the assessments through comparing the means (Shaughnessy 2006).

In this research, the effect size measures are used as the technique of comparing means. Effect size is a measure of the strength of the relationship between two variables. In scientific experiments, it is often useful to know not only whether an experiment has a statistically significant effect, but also the size of any observed
effects. The effect size is also known as partial eta-squared, \( \eta_p^2 \), which estimates of the degree of association for the sample, where

\[
\eta_p^2 = \frac{SS \text{ treatment}}{SS \text{ treatment} + SS \text{ error}} \tag{4.1}
\]

The effect size is expressed by the variance of the sums of squares for a particular effect (SS treatment) from sum of squares of that effect plus the error sum of squares (SS error). The partial eta squared is used instead of the complete eta squared because the author prefers to treat the value as a proportion from 0 to 1. The usual benchmarks for classifying the value of \( \eta_p^2 \) are represented in Table 4.8 (Kinnear 2008). This analysis is used in Chapters 5 to 8.

Table 4.8: Classification of effect size

<table>
<thead>
<tr>
<th>Partial eta-squared ( (\eta_p^2) )</th>
<th>Size of effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01 ( \leq \eta_p^2 \leq 0.06 )</td>
<td>Small</td>
</tr>
<tr>
<td>0.06 ( \leq \eta_p^2 \leq 0.14 )</td>
<td>Medium</td>
</tr>
<tr>
<td>( \eta_p^2 \geq 0.14 )</td>
<td>Large</td>
</tr>
</tbody>
</table>

iii. Friedman test

This test is suitable to identify the rank obtained from ordinal data. Ordinal data is not independent measures but consists of ranks. Similar to the ANOVA repeated measures, it is used to detect differences in treatments across multiple test attempts. The procedure involves ranking each row together, then considering the values of ranks by columns.
Friedman test is used to express the hierarchy of ranks given for each indoor condition as voted by occupants through question F.1 in Section F of the questionnaire. The highest mean rank in the Friedman test result is the most influential indoor condition and vice versa. This analysis is used in Chapter 8 only.

iv. Multiple linear regression model

Multiple linear regression model consists of one dependent variable (DV) and multiple independent variables (IVs). It is conducted to identify the effectiveness of an IV in building a relationship with the DV. The strength of each IV can be observed through its beta coefficient, t-distribution and significant test.

The beta coefficients represent the estimate of average number of standard deviations changes in the criterion that will be produced by a change of one standard deviation in the DV. In other words, the lower an IV’s beta coefficient value is, the weaker its role in the regression model. Values from t-distribution and significant test provide for the constant and regression coefficients, respectively, thus further indicate the strength of DV – IV relationship (Kinnear 2008). Similar to Friedman test, this analysis is also been used in Chapter 8 only.

4.8 Geographical, climatic and design descriptions of case study buildings

4.8.1 Geographical and climatic descriptions of case study sites

The Klang Valley is a region in Peninsula Malaysia which is about 50 km long and 25 km wide (Figure 4.12). The Valley begins in the north-east of Kuala Lumpur, the capital city of Malaysia. Klang Valley in general is a low-lying area. More than 2 million people live here which constitutes 10% of the total population of Malaysia.
This region is also the nation’s economic, social and administrative hub. The towns in the Valley make up the biggest conurbation in the whole of Malaysia. The major towns that lie within the Klang Valley are Subang, Petaling Jaya, Shah Alam, Klang, Putrajaya, and Cyberjaya.

Selected hostels are located in Petaling Jaya, Serdang and Bangi. Petaling Jaya with latitude of 3° 6’N, longitude of 101° 39’E is just 5 minutes drive to Kuala Lumpur. Petaling Jaya is 60.8m above sea level. Serdang is located to the south of Kuala Lumpur while Bangi is a new town development with one public university and one semi-public university. Meteorological data for Petaling Jaya was collected from Petaling Jaya Meteorological Station. There was no weather station in Serdang and Bangi. The nearest meteorological station to these two towns was in Kuala Lumpur International Airport (KLIA) in the Sepang district. KLIA is geographically located at latitude of 2° 44’N, longitude of 101° 42’E and is 16.3m above sea-level.

Malaysia is a country located near to the equator and receives high solar radiation. The local climate is characterized by the annual southwest (April to October) and northeast (October to February) monsoons. Map of Western and Eastern Malaysia is displayed in Figure 4.7.
The synoptic weather conditions were observed from two weather stations, namely from the Petaling Jaya and Kuala Lumpur International Airport (KLIA), situated about 30km (19 miles) apart from each other (refer to Figure 4.12). Weather conditions included are temperature, wind velocity, relative humidity, and rainfall.

The recorded monthly temperatures were 27.3°C and 27.8°C for Petaling Jaya and KLIA, respectively. Average minimum temperatures recorded were 23.9°C and 24.4°C, respectively with average maximum temperature at 32.8°C and 32.3°C (Figure 4.8 and 4.10). The average monthly relative humidity in Petaling Jaya was 79.6% which was 0.1 lesser than the one detected in KLIA. The average monthly rainfall recorded were 229 mm and 163 mm for Petaling Jaya and KLIA, respectively (Figure 4.9 and 4.11).
Figure 4.8: Monthly maximum, minimum and average temperatures in Petaling Jaya (1971-2006).
Modified from: Malaysian Meteorological Department, http://www.met.gov.my/home_e.html

Figure 4.9: Monthly maximum and average rainfall and relative humidity in Petaling Jaya (1971-2006).
Figure 4.10: Monthly maximum, minimum and average temperatures in KLIA (1998-2006).

Figure 4.11: Monthly maximum and average rainfall and relative humidity in KLIA (1998-2006).
Modified from: Malaysian Meteorological Department, http://www.met.gov.my/home_e.html
Notes: Box 1: University of Malaya (weather station: Petaling Jaya); Box 2: Universiti Putra Malaysia (weather station: KLIA); and Box 3: UNITEN (weather station: KLIA)

Figure 4.12: Klang Valley map.
Source: www.itis.com.my

Correspondences with the respective hostel managers were made in April 2007, which was prior to the data collection duration in order to obtain permission to carry out the study. The hostel managers were briefed about the measurement so that they have a clear picture of what was going to be done in the hostels and the degree of cooperation needed.
The information given to the hostel managers included the: (1) brief of building assessment survey with cover letter from the Head of the Welsh School of Architecture, Cardiff University explaining the survey, (2) measurement protocol explaining the procedure of the objective investigation and (3) sample of the questionnaire form to be answered by the occupants.

Out of five candidate buildings identified as being suitable for the study, three agreed to participate in the investigation, namely, Twelfth Residential College, Universiti Malaya (H1); Eleventh Residential College, Universiti Putra Malaysia (H2); and Murni Student Apartment, Universiti Tenaga Nasional (H3). Locations of all three hostels are shown in Figure 4.12. Building drawings and weather data were requested after confirming the candidate buildings. The dates of the objective measurements conducted for each of the three buildings were agreed within the three month university semester break that started from May until July in 2007. After the semester break, building managers were requested to notify the building occupants about the questionnaire surveys to be taken on the agreed dates.

Work schedule during the data collection duration began in May 7 until July 19, 2007, with a total of 72 working days. Information about the buildings was gathered starting from May 7 until May 11. The field measurement started with H1 for two weeks (i.e.: May 12 until May 25), H2 for four weeks (i.e.: May 27 until June 23) and H3 for two weeks (i.e.: June 24 until July 6). The questionnaire surveys were administered during the two following remaining weeks. A Gantt chart of the data collection schedule is shown in Chart 1 at the end of this chapter. Field measurement periods were broken down to two types of duration, namely the main and the sub
measurement. The main measurement consisted of the whole seven day field measurement duration allocated for each room orientation. Within the main measurement there are three groups of measurements that are considered as sub measurements, namely:

1. Measurement of air temperature, mean radiant temperature, air speed and relative humidity. Measurements were done with ceiling fan switched off.

2. Measurement of external and internal illumination and luminance from window.


All the above group of measurements were conducted at the same time throughout a three day period. Only the first group was repeated subsequently on the fourth day but with ceiling fan switched on.
4.8.2 Selected hostels

4.8.2.1 Twelfth Residential College, Universiti Malaya (H1)

Universiti Malaya, or UM, Malaysia’s oldest university, is situated on a 750 acre (309 hectare) campus in the southwest of Kuala Lumpur, the capital of Malaysia. It was established in April 1949 in Singapore with the merger of the King Edward VII College of Medicine (founded in 1905) and Raffles College (founded in 1928). The University of Malaya derives its name from the term ‘Malaya’ as the country was then known. The growth of the University was very rapid during the first decade of its establishment and this resulted in the setting up of two autonomous Divisions in 1959, one located in Singapore and the other in Kuala Lumpur. In 1960, the government of the two territories indicated their desire to change the status of the Divisions into that of a national university. Legislation was passed in 1961 and the University of Malaya was established on 1st January 1962 (http://www.um.edu.my/discover_um/history_of_um).

The 12th Residential College (H1) was selected as the first case study. It was opened in 2002 and can accommodate up to 3000 students at one time. There are 4 blocks, namely, block A and B for male and C and D for female students. A hall with a canteen block segregates block B and C but there are adjacently linked. This hostel is 9 storeys high with two lift hubs for each block. Rooms in H1 are either facing north or south. Figure 4.13 shows the site plan of H1. A large pond is made in front of the hall and canteen block. Mature trees and vegetations can be seen in most of H1 open areas. About 20m to the east of the hostel blocks is the Kerinchi Link Highway (Plate 4.12).
In terms of circulations, lift hubs are connected with open corridors. Its long floors are broken with open waiting areas that are complemented with balconies. At each end of the blocks, there are washing and airy clothes lines areas. Figure 4.14 shows typical floor layout for H1. The north elevation of H1 is shown in Plate 4.13.

The occupancy number in H1 is two students per-room. Artificial lighting such as ceiling pendaflour (fluorescent tube) lights and task lights are installed. Room finishes consisted of beige coloured plaster and paint walls, cement rendered floor and beige coloured plaster and paint ceiling. For ventilation, a ceiling fan and two adjustable louver windows are fitted. View of a typical room in H1 is shown in Plate 4.14. In H1, three rooms share one balcony (projecting 1.5m). In terms of shading strategies, rooms on the 9th floor are shaded via long roof overhangs (2.5m projection, 30° tilt) while the other rooms are shaded via the balconies above them.
Figure 4.13: Universiti Malaya campus map (not to scale). Shaded area is the Twelfth Residential College (H1). ‘Xs’ mark the location of measured rooms.

Source: Development Unit, UM

Figure 4.14: Typical floor layout for H1. Boxed locations indicate location of measured rooms.

Source: Development Unit, UM
Plate 4.12: Boxed location shows near-by high-way viewed from North facing measured room on 9th floor of H1.

Plate 4.13: Elevation of H1. Boxed locations indicate locations of measured rooms. Rooms are facing north.
4.8.2.2 Eleventh Residential College, Universiti Putra Malaysia (H2)

Universiti Putra Malaysia (UPM) was formerly known as School of Agriculture which officially instituted on 21 May, 1931 by John Scott, an administrative officer of the British colonial Straits Settlements. In 1942, it was declared to be the College of Agriculture Malaya by Sir Edward Gent, the Governor of the Malayan Union. UPM was founded in 1971 through the merger of the Faculty of Agriculture, University of Malaya and the Agriculture College in Serdang, Selangor state and located on a 22-acre spread in Serdang, Selangor (http://en.wikipedia.org/wiki/Universiti_Putra_Malaysia). Figure 4.15 shows a partial campus map of UPM.
In this university, the 11th Residential College (H2) is chosen as the second case study building. This female hostel was opened in the year 2000. Male students occupy the neighbouring 10th Residential College located to the north-west of H2. Vegetation treatment in H2 compound is only located to its south-west (football field) (Figure 4.15). The nearest building complexes are the Faculty of Engineering followed by the Faculty of Design & Architecture. H2 is also located about 100m from the North-South Highway (Plate 4.15).

H2 has 4 wings, namely, wing A, B, C & D. It can occupy up to 1000 students at one time. Lifts are located at each interlocking area between wing A & B and between wings C & D. Corridor in H2, unlike in H1 is narrower and somewhat closed. Figure 4.16 shows a typical floor plan layout for H2. The south-east elevation of H2 is shown in Plate 4.16.

The occupancy number in H2 is three students per-room. Rooms are fixed with beds, study desks and cupboards. Room finishes consists of beige coloured plaster and paint walls, cement rendered floor and beige coloured plaster and paint ceiling. One ceiling pendaflour light and one ceiling fan are fitted in each room. Rooms are arranged opposite to each other with a 1.2m wide corridor in between. Windows in H2 are not shaded. Its roof overhang is 1.0m. The rooms are designed with 6-sashes top hung casement window. View of a typical room in H2 is shown in Plate 4.17. Balconies functioned as clothes lines are shared by two rooms. The size of this balcony is relatively smaller than in H1 and made introvert in the façade (Plate 4.16).
Figure 4.15: Universiti Putra Malaysia (UPM) campus map. Boxed area is the Eleventh Residential College (H2)

Source: Development Unit, UPM
Figure 4.16: Typical floor plan layout for H2. Shaded areas indicate measured rooms.

Plate 4.15: Boxed location shows near-by high-way viewed from North-west facing measured room on 7th floor of H2.
Plate 4.16: Elevation of H2. Boxed locations indicate locations of measured rooms. Rooms are facing South-east.

Plate 4.17: Typical view of a room in H2.
4.8.2.3 Murni Student Apartment, Universiti Tenaga Nasional (H3)

Universiti Tenaga Nasional’s (UNITEN) Putrajaya campus is located about 25km south of the capital city of Kuala Lumpur near Kajang in Selangor and easily accessible via a number of highways. Nestled on a 214-hectare site situated close to the Putrajaya and Kuala Lumpur (www.uniten.edu.my/newhome/content_list.asp?ContentID=584).

Murni Student Apartment (H3) has been chosen as the third case study. (Figure 4.17). The capacity for this two blocks student apartment (block M1 and M2) is about 480 students. Each block is 10 storeys high. Apartment is fitted with lounge area, kitchenette, bedrooms, toilet and clothes line. Measurements were conducted in the lounge areas, which is indicated through the shaded area in Figure 4.18.

Lounge areas in block M1 face west while lounge areas in M2 face north. There are 8 apartments per floor. In terms of circulation, the lift hub is installed in the middle of each block. No two apartments are designed opposite to each other as arranged in H1 and H2 (Figure 4.18). A six lanes highway is located just about 70m from H3 (Plate 4.18). The west elevation of H3 is shown in Plate 4.19. View ‘A’ shows the window walls of measured areas in Block M1. View ‘B’ shows the open corridors that connected each room.

The occupancy number in H3 is four students per-room. The lounge and kitchenette area is finished with beige coloured plaster and paint walls, homogenous floor tiles and white coloured plaster and paint ceiling. One ceiling pendaflour light,
two task lights and one ceiling fan are fitted in that particular area. View of the typical room in H3 is shown in Plate 4.20.

Figure 4.17: Universiti Tenaga Nasional campus map. Xs’ mark the location of measured rooms. 
Source: Development Unit, UNITEN

Figure 4.18: Typical floor plan layout for H3. Boxed location indicates location measured room per-block.
Plate 4.18: View of near-by high-way viewed from North facing measured room on 10th floor of H3.

(a) View A
Plate 4.19: Elevations of H3. Rooms in view ‘A’ is facing west. Boxed locations indicate location of measured rooms.

Plate 4.20: Typical view of a room in H3.
4.8.3 Measured rooms specifications and location of instruments

Measured rooms in block C and D of H1 are chosen at the 1st, 5th and 9th floor (top floor) and are aligned vertically. The reflectance factor for walls, floor and ceiling are 0.6, 0.3 and 0.7, respectively (ISO8995 2002).

Figures 4.19 and 4.21 show the dimensions in plan and cross section of H1 room, respectively. Locations of sensors are indicated by positions ‘A – C’ and ‘B’ that are 2.0m from the window wall, and next to window wall, respectively. Position ‘A’ represents the location for air temperature and relative humidity probe and lux meter, position ‘B’ represents the location for airflow thermo-anemometer and digital sound pressure level meter and position ‘C’ represents the location for photometer. Figure 4.20 shows the elevation of the window wall. The closes up views of the balcony and glass louver window are shown in Plate 4.21. Room volume, window to wall ratio (WWR), operable window to wall ratio (OWWR) and shading ratio (SR) for the rooms in H1 are as follow:

i. Room volume = 5.0m (l) x 3.0m (w) x 3.0m (h) = 45m$^3$.

ii. WWR = 5.0m$^2$ (window + door areas) / 9.0m$^2$ (whole window wall) x 100 = 60%

iii. OWWR = 2.9m$^2$ (windows area) / 9.0m$^2$ (whole window wall) x 100 = 30%

iv. SR (1st & 5th floor rooms) = 1.4m (balcony above floor) / 1.6m (window height) = 0.9
v. \[ SR \text{ (Top floor room)} = \frac{2.5 \text{m} \text{ (length of roof overhang)}}{1.6 \text{m} \text{ (window height)}} = 1.6 \]
a) North facing with balcony also as overhangs for each room.

b) Glass louver window

Plate 4.21: (a) Close up of elevation of H1 and (b) louver window
Measured rooms in H2 are selected at 1st, 5th and 7th floor (top floor) facing north-east, south-east, north-west and south-west orientations. The reflectance factor for walls, floor and ceiling are 0.7, 0.3 and 0.7, respectively (ISO8995 2002).

Figures 4.22 and 4.24 show the dimensions in plan and cross section of H2 room, respectively. Locations of sensors are indicated by positions ‘A – C’ and ‘B’. Figure 4.23 shows the elevation of the widow wall. The closes up views of the elevation and top hung window are shown in Plate 4.22. Room volume, window to wall ratio (WWR), operable window to wall ratio (OWWR) and shading ratio (SR) for the rooms in H2 are as follow:

i. Room volume = 4.3m (l) x 3.7m (w) x 3.0m (h) = 48m³

ii. WWR = 2.7m² (window areas) / 11.1m² (whole window wall) x 100 = 20%

iii. OWWR = 2.2m² (openable windows area) / 11.1m² (whole window wall) x 100 = 20%

iv. SR (1st & 5th floor rooms) = no shading / 1.5m (window height) = 0

v. SR (Top floor room) = 1.0m (length of roof overhang) / 1.5m (window height) = 0.7
Figure 4.22: Dimension of H2 room and locations of sensors: ‘A’, ‘B’ and ‘C’.

Figure 4.23: View A in H2 room.
Figure 4.24: Section X - X’ of H2 room

Plate 4.22: (a) Close up of elevation of H2 and (b) top hung windows

a) South facing with introvert balconies balcony b) Top hung windows

Measured areas in H3 are selected at 1st, 5th and 10th floor (top floor) facing north and west orientations. The reflectance factor for walls, floor and ceiling are 0.7, 0.6 and 0.7, respectively (ISO8995 2002). The first window design is consists of two
side-hung case window with one fixed sash. Only the lounge areas on the 10th floor are shaded via roof overhang (1.0m projection). The second window is consists of two side-hung casement windows and shaded via the corridor above them (2.5m projection) (Plate 4.19b).

Figures 4.25 and 4.27 show the dimensions in plan and cross section of H3 room, respectively. Locations of sensors are indicated by positions ‘A – C’ and ‘B’. Figure 4.26 shows the elevation of the window wall. The closes up views of the elevation and side hung window are shown in Plate 4.23. Room volume, window to wall ratio (WWR), operable window to wall ratio (OWWR) and shading ratio (SR) for the rooms in H3 are as follow:

i. Room volume = 6.5m (l) x 5.3m (w) x 3.0m (h) = 103m³

ii. WWR = 3.2m² (window areas) / 8.4m² (whole window wall) x100 = 40%

iii. OWWR = 1.8m² (openable windows area) / 8.4m² (whole window wall) x100 = 20%

iv. SR (1st & 5th floor rooms) = no shading / 1.5m (window height) = 0

v. SR (Top floor room) = 1.0m (length of roof overhang) / 1.8m (window height) = 0.6
Figure 4.25: Dimension of H3 room and locations of sensors: 'A', 'B' and 'C'.

Figure 4.26: View A in H3 room.
Figure 4.27: Section X - X' of H3 room

Plate 4.23: (a) Close up of elevation of H3 and (b) side hung windows

a) West facing with balcony.  
b) Side hung windows
The summary for the inventory of the case study hostels is shown in Table 4.9.

Table 4.9: Summary of Case Study Inventory

<table>
<thead>
<tr>
<th>Case study Buildings</th>
<th>12th Residential College, UM (H1)</th>
<th>11th Residential College, UPM (H2)</th>
<th>Murni Student Apartment, UNITEN (H3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field measurement</td>
<td>12/05 - 25/05 (2 weeks)</td>
<td>27/05 - 23/06 (4 weeks)</td>
<td>24/06 - 06/06 (2 weeks)</td>
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<td>Room Orientation</td>
<td>North &amp; South</td>
<td>South-east, South-west, North-east &amp; North-west</td>
<td>West &amp; North</td>
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<tr>
<td>Room Dimension</td>
<td>5.0(l) x 3.0(w) x 3.0(h)</td>
<td>4.3(l) x 3.7(w) x 3.0(h)</td>
<td>6.5(l) x 5.3(w) x 3.0(h)</td>
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<tr>
<td>Room Volume</td>
<td>45m³</td>
<td>48m³</td>
<td>103m³</td>
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<td>Floor Area</td>
<td>15m²</td>
<td>16m²</td>
<td>34m²</td>
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<td>Floor level (excluding ground floor)</td>
<td>9</td>
<td>7</td>
<td>10</td>
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<td>Occupant per-room</td>
<td>Max. 2</td>
<td>Max. 3</td>
<td>Max. 4</td>
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<td>Window Area</td>
<td>2.9m²</td>
<td>2.7m²</td>
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<td>Window to Wall Ratio (WWR)</td>
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<tr>
<td>Operable window to Wall Ratio (OWWR)</td>
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<td>20%</td>
<td>20%</td>
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<td>Shading Ratio</td>
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<td>0.7 (top floor); 0.0 (1st &amp; 5th floor)</td>
<td>0.6 (top floor); 0.0 (1st &amp; 5th floor)</td>
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<td>Window Design</td>
<td>Adjustable Glass Louver</td>
<td>Top Hung casement window (6 sashes)</td>
<td>1) 2 Side Hung &amp; 1 Fixed case window (3 sashes)</td>
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<td>2.0m (from window)</td>
<td>3.6m (from window)</td>
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<td>0.3 (cement render)</td>
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### DATA COLLECTION WORK SCHEDULE: 7th May until 19th July 2007

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<th>JUNE</th>
<th>JULY</th>
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<td>1.2 Get for drawings of hostels</td>
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<td>1.3 Get weather data from Weather Stations</td>
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<td>2.3.2.3 L_Aeq(1)</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.3.2.4 Fan; Ta, Tr, AV, RH, Tis, Tes</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.0 Questionnaire survey</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.1 Distribute to occupants in H1</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.2 Distribute to occupants in H2</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.3 Distribute to occupants in H3</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL DATA COLLECTION DAYS</td>
<td>72</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Symbols and legends are included in the following page.

Gantt chart: 1 (For explanation of the chart, refer to pages 34-35 of this chapter)
### Symbols/ Legends:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>🟢</td>
<td>Permission and info on hostels</td>
<td>AV</td>
</tr>
<tr>
<td>🟥</td>
<td>Main (Objective Measurement)</td>
<td>RH</td>
</tr>
<tr>
<td>🟦</td>
<td>Sub (Objective Measurement)</td>
<td>Tis</td>
</tr>
<tr>
<td>🔵</td>
<td>Questionnaire survey</td>
<td>Tes</td>
</tr>
<tr>
<td>Ta</td>
<td>Air temperature</td>
<td>Eout</td>
</tr>
<tr>
<td>Tr</td>
<td>Mean radiant temperature</td>
<td>Ein</td>
</tr>
<tr>
<td>L_Aeq(1)</td>
<td>Noise equivalent in one hour</td>
<td>Lw</td>
</tr>
</tbody>
</table>

The overall research procedure flow is summarised in Figure 4.28 (turn to next page). This flow is divided into three stages that consisted of preliminary works, actual measurements and analyses using statistics.
RESEARCH PROCEDURE FLOW

STAGE 1

Preliminary Works: Tower Hall, Cardiff University

Measurements:
- **Objective:** Air temp., M.R.T., Rel. Humidity, Airspeed.
- **Subjective:** Thermal, visual & acoustics comfort

Revised on procedures:
- Objective
- Subjective

Instruments:
- Objective: temperature sensors & anemometer
- Subjective: Questionnaire survey

STAGE 2

Actual measurements: H1, H2 & H3

Objective
- Identify: Sky condition, External illumination
- Thermal
- Visual
- Acoustic

Investigations:
- 7 days x 2 room orientations (H1)
- 7 days x 4 room orientations (H2)
- 7 days x 2 room orientations (H3)

Questionnaire survey:
- Component 1 (thermal, visual & acoustics comfort survey)
- Component 2 (overall indoor comfort survey)

STAGE 3

Analyses: Statistics

Occupants' overall indoor comfort?

Results:
- **Objective**
  - (1) Descriptive analysis; (2) ANOVA
- **Subjective**
  - (1) Descriptive analysis; (2) ANOVA
- **Objective & Subjective**
  - (1) Multiple linear regression; (2) ANOVA
  - (3) Friedman Tests

Cross-examined with:
- Dry bulb temp.
- RD & CD
- Daytime period
- Floor level
- WWR
- Room Orientation

To answer this question, the following indoor comfort are investigated

Thermal
- Op. temp
- DR & Luminance

Visual
- External illumination, RD & CD, Daytime Period
- Floor level, WWR, Room Orientation

Acoustic
- SPL

Figure 4.28: Research Procedure Flow
Summary

In this chapter, the research methodologies employed are discussed. Measurement procedures and instrumentations used for four types of assessments, namely thermal, visual, acoustic and integrated indoor comfort factors investigations are included.

Results for each type of assessments are explained in four separate chapters. The chapters are namely, Chapter 5: Operative temperature and thermal comfort assessments; Chapter 6: Daylight ratio, luminance of window and visual comfort assessments; Chapter 7: Indoor environmental noise level and acoustic comfort assessments; and Chapter 8: Overall indoor comfort satisfaction assessments.
CHAPTER 5

OPERATIVE TEMPERATURE AND THERMAL COMFORT ASSESSMENTS

5.1 Introduction

This chapter is dedicated to describe results obtained from thermal assessments conducted through objective and subjective measurements. The objectives for this chapter are as follows:

i. To comprehensively measure the indoor and outdoor microclimate condition of selected hostel samples in regards to ceiling fan usage.

ii. To assess subjective thermal sensation experienced by occupants via questionnaire survey.

5.2 Results: Objective thermal measurements

5.2.1 Outdoor microclimate

Outdoor microclimate data consisting of air temperature, relative humidity, and wind speed at case study sites from May 12 until July 6, 2007 are displayed in Figures 5.1 to 5.3. Over the 56-day objective measurement period, the recorded average temperatures were 28.2°C, 27.3°C and 28.3°C with average humidity of 76.7%, 82.4% and 76.8% for H1, H2 and H3, respectively. Meanwhile, the average wind speed was around 1.7 m/s for all three case study sites. In sum, the outdoor air
Operative Temperature and Thermal Comfort Assessments

temperature, and relative humidity during the measurement period closely resemble the typical average temperature (i.e.: ~ 28°C) and relative humidity (i.e.: ~ 80%) for Petaling Jaya and KLIA (Figures 4.8 to 4.11).
Figure 5.1: Daily maximum, minimum & average in H1 for: (a) Temperature; (b) Relative Humidity; & (c) Wind Speed.

Figure 5.2: Daily maximum, minimum & average in H2 for: (a) Temperature; (b) Relative Humidity; & (c) Wind Speed.
Figure 5.3: Daily maximum, minimum & average in H3 for: (a) Temperature; (b) Relative Humidity; & (c) Wind Speed.
Table 5.1 shows the list of Rainy and Clear Days throughout the measurement period.

Table 5.1: List of Rainy and Clear days during objective measurement period

<table>
<thead>
<tr>
<th>Dates</th>
<th>Case study</th>
<th>Rainy days</th>
<th>Clear days</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1</td>
<td>13th May</td>
<td>12th May</td>
<td></td>
</tr>
<tr>
<td></td>
<td>19th May</td>
<td>14th May</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20th May</td>
<td>21st May</td>
<td></td>
</tr>
<tr>
<td>H2</td>
<td>28th May</td>
<td>27th May</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3rd June</td>
<td>29th May</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4th June</td>
<td>12th June</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5th June</td>
<td>18th June</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10th June</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>11th June</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>17th June</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>19th June</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H3</td>
<td>25th June</td>
<td>24th June</td>
<td></td>
</tr>
<tr>
<td></td>
<td>26th June</td>
<td>1st July</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2nd July</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3rd July</td>
<td></td>
</tr>
</tbody>
</table>

It is observed that outdoor air temperature in Clear Day was about 1°C warmer than Rainy Day with large effect size of partial eta squared ($\eta^2_p$) above 0.14 (Table 5.2). This is because rainy days receives outburst of precipitation that reduces air temperature (Oke 1978). The relative humidity for Clear Day was about 5% lower than in Rainy Day. However, because the saturated pressure of water at the temperature for Rainy and Clear Days was 4.24 kPa, as referred to vapour pressure of water when the temperature was 30°C (i.e.: RD = 28°C and CD = 27°C) (Rotronic 2005), not much actual partial pressure of water was detected, namely 3.4 kPa and 3.3 kPa for Rainy and Clear Day, respectively.

Table 5.2: Dry bulb temperature ($T_{\text{out}}$) and relative humidity (RH) mean differences during rainy day (RD) and clear day (CD) using ANOVA repeated measures

<table>
<thead>
<tr>
<th>Day</th>
<th>Mean</th>
<th>S.D</th>
<th>$\eta^2_p$</th>
<th>Significant</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{\text{out}}$ °C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CD</td>
<td>28.3</td>
<td>±2.7</td>
<td>0.22</td>
<td>$p &lt; 0.01$</td>
</tr>
<tr>
<td>RD</td>
<td>27.3</td>
<td>±2.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RH, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CD</td>
<td>77.0</td>
<td>±12.1</td>
<td>0.22</td>
<td>$p &lt; 0.01$</td>
</tr>
<tr>
<td>RD</td>
<td>82.1</td>
<td>±10.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5.2.2 Operative temperature measurements: without ceiling fan

Statistical summary of the meteorological data during the measured period is shown in Table 5.3. Measured room indications, such as, ‘H1N’; ‘H1S’; ‘H2SE’ and etc. are made as reference to which set of meteorological data they belong to. Dry bulb temperature recorded ranges from 24 to 34°C. The most constant dry bulb temperature was from June 10 to 12, which was recorded when measuring rooms in H2 facing North-east (s.d. = ±1.2°C) and the least constant one was from May 12 to 14 as recorded when measuring rooms in H1 facing North (s.d. = ±2.9°C). Wind direction during measurement period is shown in Chapter 7, Table 7.1.

Table 5.3: Statistical summary of dry bulb temperature, relative humidity and wind speed during measurement period (no fan)

<table>
<thead>
<tr>
<th>Weather data collected from Petaling Jaya and KLIA meteorological station</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>H1N</strong> (12 – 14 May)</td>
</tr>
<tr>
<td>$T_{out}$ (°C)</td>
</tr>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>Min.</td>
</tr>
<tr>
<td>Max.</td>
</tr>
<tr>
<td>S. d.</td>
</tr>
</tbody>
</table>

| **H2NE** (10 – 12 June) | **H2 NW** (17-19 June) | **H3W** (24 – 26 June) | **H3N** (1 – 3 July) |
| $T_{out}$ (°C) | RH (%) | WS (m/s) | $T_{out}$ (°C) | RH (%) | WS (m/s) | $T_{out}$ (°C) | RH (%) | WS (m/s) |
| Mean | 29.5 | 73.5 | 2.1 | 29.4 | 70.7 | 2.7 | 29.5 | 73.8 | 12.3 |
| Min. | 25.5 | 65.0 | 0.7 | 25.3 | 54.0 | 0.8 | 25.3 | 62.0 | 0.6 |
| Max. | 31.2 | 91.0 | 3.5 | 33.0 | 91.0 | 4.9 | 31.9 | 93.0 | 4.2 |
| S. d. | 1.2 | 6.2 | 0.9 | 2.1 | 10.3 | 1.0 | 1.8 | 8.8 | 1.0 |

Notes: $T_{out} =$ dry bulb temperature; RH = relative humidity; WS = wind speed.

Table 5.4 shows the summary of operative temperature measured when the ceiling fans were switched off for 24 hostel rooms in H1, H2 and H3. Observations from Table 5.3 and 5.4 indicate that there are differences of operative temperature readings between shaded and un-shaded rooms. Shaded rooms in H1 especially for
south oriented rooms, display a more constant operative temperature distribution of ±0.8°C for all three measured rooms. Higher mean operative temperature for north facing rooms in H1 were partially caused due to higher dry bulb temperature. Meteorological data collected (Table 5.3) shows higher dry bulb temperature recorded from May 12 to 14, 2007 for H1 North rooms compared to H1 South rooms, which was taken 4 days later. However, despite this particular condition the operative temperature for H1 North rooms remains relatively constant (s.d. = ±1.0°C) for all its three floor levels.

Un-shaded rooms in H2 show wider operative temperature swings than in H3. The highest was detected in North-west facing rooms (s.d. from ±1.6 °C to ±2.3°C). This indicates that H2 North-west rooms, especially on the top floor have the coolest and warmest operative temperature. However, both west and north facing rooms in H3 show a more constant temperature swing than recorded in H2 even though both of these hostels were un-shaded. It could be suggested that the wider temperature distribution in H2 rooms was partially influenced by their smaller room volume (i.e.: 48 m³) compared to H3 rooms (i.e.: 103 m³).

Therefore it can be suggested that rooms with shading ratio from 0.9 to 1.6, operable window to wall ratio of 0.3 and room volume below 50 m³ succeeded in passively controlling the operative temperature swing compared to un-shaded rooms. The mean operative temperatures for all 24 rooms do not differ significantly from each other, either shaded or not. Room orientation also has little effect towards the mean operative temperature when fan was switched off.
Table 5.4: Statistical summary of operative temperature for each hostel (no fan).

| Orientation | H1 Mean | H2 Mean | H3 Mean | 1\(^{st}\) flr | 5\(^{th}\) flr | 9\(^{th}\) flr | 1\(^{st}\) flr | 5\(^{th}\) flr | 7\(^{th}\) flr | 1\(^{st}\) flr | 5\(^{th}\) flr | 10\(^{th}\) flr |
|-------------|---------|---------|---------|----------------|-------------|---------|---------|-------------|-----------|---------|-------------|-----------|---------|
| North       |         |         |         | 29.6 | 30.1 | 30.3 | -      | -          | -           | 30.9 | 30.9 | 30.7 |         |         |
|             | 25\(^{th}\) perc. |         |         | 28.8 | 29.4 | 29.6 | -      | -          | -           | 30.8 | 30.7 | 30.5 |         |         |
|             | Min     |         |         | 27.0 | 28.1 | 28.1 | -      | -          | -           | 30.0 | 29.8 | 29.4 |         |         |
|             | 75\(^{th}\) perc. |         |         | 30.6 | 31.0 | 31.2 | -      | -          | -           | 31.1 | 31.0 | 30.8 |         |         |
|             | Max     |         |         | 31.9 | 32.5 | 32.3 | -      | -          | -           | 32.0 | 32.0 | 31.9 |         |         |
|             | S.D     |         |         | ±1.2 | ±1.0 | ±1.0 | -      | -          | -           | ±1.1 | ±1.2 | ±1.4 |         |         |
| South       |         |         |         | 28.5 | 28.7 | 29.5 | -      | -          | -           | -     | -     | -     |         |         |
|             | 25\(^{th}\) perc. |         |         | 27.8 | 28.1 | 28.9 | -      | -          | -           | 28.5 | 28.7 | 28.8 |         |         |
|             | Min     |         |         | 27.1 | 27.5 | 27.9 | -      | -          | -           | 27.5 | 27.9 | 27.6 |         |         |
|             | 75\(^{th}\) perc. |         |         | 29.1 | 29.3 | 30.1 | -      | -          | -           | 30.0 | 30.0 | 30.5 |         |         |
|             | Max     |         |         | 30.2 | 30.6 | 31.4 | -      | -          | -           | 31.9 | 31.4 | 33.6 |         |         |
|             | S.D     |         |         | ±0.8 | ±0.8 | ±0.8 | -      | -          | -           | ±1.0 | ±0.8 | ±1.2 |         |         |
| West        |         |         |         | -     | -     | -     | -      | -          | -           | 29.3 | 29.3 | 29.7 |         |         |
|             | 25\(^{th}\) perc. |         |         | -     | -     | -     | -      | -          | -           | 28.5 | 28.7 | 28.8 |         |         |
|             | Min     |         |         | -     | -     | -     | -      | -          | -           | 27.5 | 27.9 | 27.6 |         |         |
|             | 75\(^{th}\) perc. |         |         | -     | -     | -     | -      | -          | -           | 30.0 | 30.0 | 30.5 |         |         |
|             | Max     |         |         | -     | -     | -     | -      | -          | -           | 31.9 | 31.4 | 33.6 |         |         |
|             | S.D     |         |         | -     | -     | -     | -      | -          | -           | ±1.0 | ±0.8 | ±1.2 |         |         |
| South-East  |         |         |         | -     | -     | -     | 28.4 | 29.1 | 29.4 | -           | - | - | - |         |         |
|             | 25\(^{th}\) perc. |         |         | -     | -     | -     | 28.0 | 28.6 | 28.6 | -           | - | - | - |         |         |
|             | Min     |         |         | -     | -     | -     | 26.8 | 27.4 | 27.0 | -           | - | - | - |         |         |
|             | 75\(^{th}\) perc. |         |         | -     | -     | -     | 29.0 | 29.6 | 30.4 | -           | - | - | - |         |         |
|             | Max     |         |         | -     | -     | -     | 29.9 | 30.7 | 31.7 | -           | - | - | - |         |         |
|             | S.D     |         |         | -     | -     | -     | ±0.7 | ±0.7 | ±1.1 | -           | - | - | - |         |         |
| South-West  |         |         |         | -     | -     | -     | 28.4 | 28.6 | 28.7 | -           | - | - | - |         |         |
|             | 25\(^{th}\) perc. |         |         | -     | -     | -     | 27.5 | 27.8 | 27.8 | -           | - | - | - |         |         |
|             | Min     |         |         | -     | -     | -     | 26.5 | 26.7 | 26.6 | -           | - | - | - |         |         |
|             | 75\(^{th}\) perc. |         |         | -     | -     | -     | 29.0 | 29.3 | 29.5 | -           | - | - | - |         |         |
|             | Max     |         |         | -     | -     | -     | 31.3 | 31.2 | 32.6 | -           | - | - | - |         |         |
|             | S.D     |         |         | -     | -     | -     | ±1.1 | ±1.1 | ±1.4 | -           | - | - | - |         |         |
| North-West  |         |         |         | -     | -     | -     | 29.1 | 29.0 | 29.1 | -           | - | - | - |         |         |
|             | 25\(^{th}\) perc. |         |         | -     | -     | -     | 27.9 | 27.9 | 27.7 | -           | - | - | - |         |         |
|             | Min     |         |         | -     | -     | -     | 26.6 | 26.2 | 26.5 | -           | - | - | - |         |         |
|             | 75\(^{th}\) perc. |         |         | -     | -     | -     | 30.1 | 30.0 | 30.3 | -           | - | - | - |         |         |
|             | Max     |         |         | -     | -     | -     | 36.3 | 36.2 | 41.0 | -           | - | - | - |         |         |
|             | S.D     |         |         | -     | -     | -     | ±1.7 | ±1.6 | ±2.3 | -           | - | - | - |         |         |
| North-east  |         |         |         | -     | -     | -     | 29.8 | 29.6 | 29.7 | -           | - | - | - |         |         |
|             | 25\(^{th}\) perc. |         |         | -     | -     | -     | 28.7 | 28.3 | 28.1 | -           | - | - | - |         |         |
|             | Min     |         |         | -     | -     | -     | 27.7 | 27.0 | 26.8 | -           | - | - | - |         |         |
|             | 75\(^{th}\) perc. |         |         | -     | -     | -     | 30.9 | 30.9 | 31.4 | -           | - | - | - |         |         |
|             | Max     |         |         | -     | -     | -     | 32.5 | 32.4 | 33.1 | -           | - | - | - |         |         |
|             | S.D     |         |         | -     | -     | -     | ±1.3 | ±1.5 | ±1.8 | -           | - | - | - |         |         |

Note: '-' indicating no data.
A summary of the mean operative temperature without fan measured at different floor levels is shown in Figure 5.4. Lower and middle floor rooms in H1, H2 and H3 were measured at 3m (i.e.: 1st floor), 15m (i.e.: 5th floor) above ground, respectively. The top floor rooms for H1, H2 and H3 were measured at 27m, 21m and 30m above ground, respectively. Number of rooms in H1, H2 and H3 per-floor were 6, 12 and 6, respectively. It can be observed that operative temperature increases with the vertical room location, especially for H1. Rooms in H1 showed about 0.4°C increment as the floor level increases. Rooms in H2 show constant operative temperature in rooms located on the first and fifth floor because these rooms were shaded by adjacent hostel wings. Meanwhile, rooms located on the top floor of H2 did not receive any shade thus explains why there is an increase in their operative temperature. All H3 rooms that were un-shaded were measured with constant operative temperature at about 31°C.

Surprisingly, despite the fact that, rooms on the top floor of H1 were heavily shaded (i.e.: shading ratio of 1.6), a higher operative temperature (i.e.: 30.3°C) compared to its other two lower floors was still recorded. However, when it is compared to the operative temperature measured in H3 top floor rooms (with shading ratio of 0.6), H1 top floor rooms were about 1°C cooler. H2 top floor rooms, appear to show similar temperature with H1 top floor rooms. Meanwhile, H3 top floor rooms that were located 9m higher than H2 rooms show much higher operative temperature. It can be suggested that although rooms with balcony or long overhangs show increase in operative temperature in relation to increase in vertical room location, but still show lower operative temperature than rooms that were not shaded at all. Un-shaded rooms could remain warm regardless of its vertical room location. This
Operative temperature and Thermal Comfort Assessments

investigation has shown the importance of installing shading device in typical multi-storey hostels in Malaysia in order to control the operative temperature.

![Operative temperature (no fan) at different vertical room locations](image)

Figure 5.4: Mean Operative Temperature without fan at different vertical room locations in H1, H2 and H3.

Figure 5.5 shows the operative temperature collected at different room orientations in H1, H2 and H3. Each room orientation has three measured rooms. It can suggest that rooms that are shaded (i.e.: H1 North facing rooms) received lower operative temperature compared to rooms that are not (i.e.: H3 North facing rooms). Dry bulb temperature during the measurement periods for H1 North (Figure 5.5a) and H3 North (Figure 5.5c) rooms were similar, namely about 31°C (Table 5.3), thus indicates that rooms shaded by balcony succeeded in controlling the operative temperature than un-shaded rooms.

Therefore, it can be concluded that north room orientation does not show lesser operative temperature compared to west and east facing rooms. Additional
Pearson correlation test indicates that the operative temperature in all measured rooms show a weak relationship with room orientation (i.e.: \( r = 0.07; p<0.05 \)).

![Figure 5.5: Mean Operative Temperature without fan at different room orientation in: (a) H1; (b) H2 and (c) H3.]

In looking at the influence of shading device to operative temperature during Rainy and Clear Days, ANOVA repeated measures was used to calculate the mean differences calculated in the measured rooms during Rainy and Clear Days (Table 5.5). List of Rainy and Clear Days can be referred to in Table 5.1. Mean operative temperature are significantly different beyond \( p<0.01 \) level. According to weather type influences on the hostels rooms (column of Table 5.5), the mean difference between the operative temperature in H1, H2 and H3 during Rainy Day show lesser size effect than during Clear Day. This was because H3 rooms in Clear Day differ from the other two hostels in the same weather condition, whereas during the Rainy Day very slight temperature differences were recorded. This shows that H3 rooms received higher operative temperature in Clear Day but lesser temperature increase in Rainy Day compared to other hostel rooms.
Further tests on different case studies (row of Table 5.5), show that the largest operative temperature difference between Rainy and Clear Days is detected in H3, and then followed by H2 and finally H1. Based on this finding, it could be proposed that rooms with large volume (i.e.: H3 rooms, 103m³) were more likely to display wider mean temperature difference between Rainy and Clear Days compared to smaller room volumes (i.e.: H1 rooms, 45m³; and H2 rooms, 48m³).

Table 5.5: ANOVA repeated measures of operative temperature during rainy and clear day in H1, H2 and H3

<table>
<thead>
<tr>
<th>Case</th>
<th>Mean operative temperature (°C) for different weather types</th>
<th>$\eta_p^2$ according to Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rainy day</td>
<td>Clear day</td>
</tr>
<tr>
<td>H1</td>
<td>29.0 (s.d = 1.1)</td>
<td>29.5 (s.d = 1.3)</td>
</tr>
<tr>
<td>H2</td>
<td>28.5 (s.d = 1.0)</td>
<td>29.1 (s.d = 1.2)</td>
</tr>
<tr>
<td>H3</td>
<td>29.3 (s.d = 1.0)</td>
<td>30.2 (s.d = 1.2)</td>
</tr>
</tbody>
</table>

Operative temperatures in H1, H2 and H3 at three different daytime periods were examined and presented in Table 5.6. All of the mean temperature differed significantly beyond $p<0.01$ level from one another with large effect sizes (i.e.: $\eta_p^2 >0.14$). The mean temperature difference among the three daytime periods in H1, H2 and H3, ascended from morning to evening (column of Table 5.6). This indicates that all three hostels show closer temperature resemblance in the morning but then gradually differ as the daytime progresses. Surprisingly, instead of presenting a lesser mean temperature difference in the evening, the result have revealed otherwise, because of a high mean temperature detected in H3 rooms.
Based on the case studies (row of Table 5.6), the largest mean difference is detected in H3 rooms, and then followed by H2 and H1 rooms. H3 rooms show a large mean temperature difference between its morning and evening temperatures compared to other rooms, perhaps partially due to their larger room volume but small operable window to wall ratio, i.e.: 0.2. This shows that H3 rooms were more likely to be warmer in the evening, whereas H1 and H2 rooms would probably receive more constant temperature distribution throughout the day.

Table 5.6: Summary of mean estimation for operative temperature in the morning (8:00 am to 11:59 am), afternoon (12:00 pm to 2:59 pm) and evening (3:00 pm to 5:59pm) in H1, H2 & H3.

<table>
<thead>
<tr>
<th>Case</th>
<th>Mean operative temperature (°C) for different Daytime period</th>
<th>η² according to Daytime period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Morning</td>
<td>Afternoon</td>
</tr>
<tr>
<td>H1</td>
<td>29.5 (s.d = ±1.0)</td>
<td>30.6 (s.d = ±0.8)</td>
</tr>
<tr>
<td>H2</td>
<td>28.9 (s.d = ±0.9)</td>
<td>29.8 (s.d = ±0.8)</td>
</tr>
<tr>
<td>H3</td>
<td>29.8 (s.d = ±0.9)</td>
<td>31.2 (s.d = ±0.9)</td>
</tr>
</tbody>
</table>

5.2.3 Indoor temperatures measurements: with ceiling fan

Statistical summary of the meteorological data during the measurement period with ceiling fan switched on is shown in Table 5.7. Measurement started in H1 north oriented rooms on May 16, 2007 while the final measurement was conducted in H3 north oriented rooms on July 6, 2007.
Table 5.7: Statistical summary of dry bulb temperature, relative humidity and wind speed during measurement period (with fan)

Weather data collected from Petaling Jaya and KLIA meteorological station

<table>
<thead>
<tr>
<th></th>
<th>H1N (16-18 May)</th>
<th>H1S (24-26 May)</th>
<th>H2SE (31-2 June)</th>
<th>H2SW (6-8 June)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tout</td>
<td>T&lt;sub&gt;out&lt;/sub&gt;</td>
<td>RH</td>
<td>WS</td>
<td>T&lt;sub&gt;out&lt;/sub&gt;</td>
</tr>
<tr>
<td>°C</td>
<td>°C</td>
<td>%</td>
<td>m/s</td>
<td>°C</td>
</tr>
<tr>
<td>Mean</td>
<td>27.3</td>
<td>80.0</td>
<td>1.6</td>
<td>28.7</td>
</tr>
<tr>
<td>Min.</td>
<td>23.4</td>
<td>55.0</td>
<td>0.0</td>
<td>24.6</td>
</tr>
<tr>
<td>Max.</td>
<td>32.6</td>
<td>96.0</td>
<td>4.3</td>
<td>34.3</td>
</tr>
<tr>
<td>S. D.</td>
<td>2.3</td>
<td>11.5</td>
<td>1.1</td>
<td>2.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>H2NE (13-15 June)</th>
<th>H2 NW (20-22 June)</th>
<th>H3W (27-29 June)</th>
<th>H3N (4-6 July)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tout</td>
<td>T&lt;sub&gt;out&lt;/sub&gt;</td>
<td>RH</td>
<td>WS</td>
<td>T&lt;sub&gt;out&lt;/sub&gt;</td>
</tr>
<tr>
<td>°C</td>
<td>°C</td>
<td>%</td>
<td>m/s</td>
<td>°C</td>
</tr>
<tr>
<td>Mean</td>
<td>27.2</td>
<td>83.3</td>
<td>1.9</td>
<td>28.0</td>
</tr>
<tr>
<td>Min.</td>
<td>24.3</td>
<td>58.0</td>
<td>0.0</td>
<td>24.5</td>
</tr>
<tr>
<td>Max.</td>
<td>32.0</td>
<td>98.0</td>
<td>4.3</td>
<td>32.9</td>
</tr>
<tr>
<td>S. D.</td>
<td>2.2</td>
<td>11.5</td>
<td>1.0</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Notes: T<sub>out</sub> = dry bulb temperature; RH = relative humidity; WS = wind speed.

Table 5.8 shows the summary of operative temperature with fan switched on in H1, H2 and H3 with a total of 24 rooms. In overall, the operative temperature in this condition is more constant than when the fan was switched off. However, the mean operative temperature show similar to the values obtained when no fan was switched on in Table 5.4 (i.e.: 29°C to 32°C). In order to investigate the different indoor climate between operative temperature with and without fan, the air speed during those conditions was monitored as well.

A comparison of air speed in rooms with and without fan is presents Table 5.9. H1 rooms are shown to have increased the air speed to around 1m/s when the fans were used. Meanwhile, up to 1.4m/s increment in air speed was detected in H2 rooms. However, no increase in air speed was recorded in any H3 room. It seems that ceiling fan usage was not sufficient enough to increase air speed in large volume rooms like...
in H3 than the rooms in H1 and H2. Therefore it can be revealed that ceiling fan was good at maintaining the operative temperature and provide more air movement in rooms. However, one ceiling fan per-room could not increase the air speed in room with large volume, as observed in H3 rooms.

Shaded rooms were observed to have more controlled operative temperature compared to un-shaded ones, except for rooms located at 1st and 5th floor in H2 South-east, where these rooms were shaded by adjacent hostel wing (Figure 4.16). Shaded rooms were also less influenced by their outdoor dry bulb temperature, as shown in the case of H1 South rooms that were measured during the hottest days (Table 5.7) but still manage to maintain their mean operative temperature at 30°C and below. On the contrary, when a similar dry bulb temperature was experienced in un-shaded rooms, like in the case of H3 North facing rooms, the mean operative temperature range was high, namely within 30°C to 32°C. But by switching on the ceiling fan, the operative temperature swing was controlled; namely, steadily remain around s.d = ±1.0°C compared to s.d = ±1.4°C (Table 5.4) when the fan was switched off. From these results, it confirms that shaded rooms still manage to control the operative temperature distribution even though with the fan switched on compared to un-shaded rooms.
### Table 5.8: Statistical summary of operative temperature for each hostel (with fan).

<table>
<thead>
<tr>
<th>Orientation</th>
<th>H1</th>
<th>H2</th>
<th>H3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1st flr</td>
<td>5th flr</td>
<td>9th flr</td>
</tr>
<tr>
<td>North</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>28.7</td>
<td>28.8</td>
<td>29.1</td>
</tr>
<tr>
<td>25th perc.</td>
<td>28.2</td>
<td>28.2</td>
<td>28.5</td>
</tr>
<tr>
<td>Min</td>
<td>26.9</td>
<td>27.3</td>
<td>27.3</td>
</tr>
<tr>
<td>75th perc.</td>
<td>29.1</td>
<td>29.3</td>
<td>29.6</td>
</tr>
<tr>
<td>Max</td>
<td>30.2</td>
<td>30.2</td>
<td>30.5</td>
</tr>
<tr>
<td>S.D</td>
<td>±0.6</td>
<td>±0.7</td>
<td>±0.7</td>
</tr>
<tr>
<td>South</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>29.6</td>
<td>29.8</td>
<td>30.4</td>
</tr>
<tr>
<td>25th perc.</td>
<td>29.1</td>
<td>29.3</td>
<td>30.0</td>
</tr>
<tr>
<td>Min</td>
<td>28.0</td>
<td>28.3</td>
<td>28.5</td>
</tr>
<tr>
<td>75th perc.</td>
<td>30.1</td>
<td>30.4</td>
<td>31.1</td>
</tr>
<tr>
<td>Max</td>
<td>30.9</td>
<td>31.3</td>
<td>31.9</td>
</tr>
<tr>
<td>S.D</td>
<td>±0.7</td>
<td>±0.7</td>
<td>±0.8</td>
</tr>
<tr>
<td>West</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>25th perc.</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Min</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>75th perc.</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Max</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>S.D</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>South-East</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>25th perc.</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Min</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>75th perc.</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Max</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>S.D</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>South-West</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>25th perc.</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Min</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>75th perc.</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Max</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>S.D</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>North-West</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>25th perc.</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Min</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>75th perc.</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Max</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>S.D</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**Note:** ‘-’ indicating no data.
Table 5.9: Statistical summary of air speed for each hostel with and without fan usage.

<table>
<thead>
<tr>
<th>Air speed (with and without fan usage), m/s</th>
<th>H1</th>
<th>H2</th>
<th>H3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orientation</td>
<td>1st flr</td>
<td>5th flr</td>
<td>9th flr</td>
</tr>
<tr>
<td>North</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Mean (f)</td>
<td>0.2</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>S.D</td>
<td>0.2</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Mean (n.f)</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>S.D</td>
<td>0.2</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>South</td>
<td>0.3</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Mean (n.f)</td>
<td>0.2</td>
<td>0.3</td>
<td>0.2</td>
</tr>
<tr>
<td>S.D</td>
<td>0.2</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>West</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Mean (f)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>S.D</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Mean (n.f)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>S.D</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>West</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Mean (f)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>S.D</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Mean (n.f)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>S.D</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Note: '-' indicating no data; f = with fan & n.f = no fan.

A summary of the mean operative temperature with fan measured at different floor levels is shown in Figure 5.6. It can be observed that the mean operative temperature is not affected by the floor levels in each hostel.
Figure 5.6: Mean operative temperature with fan at different vertical room locations in H1, H2 and H3.

Figure 5.7 also shows that mean operative temperatures when fans were switched on are not influenced by the room orientations.

Figure 5.7: Mean Operative Temperature with fan at different room orientation in: (a) H1; (b) H2 and (c) H3.

The comparisons between operative temperature with and without fan usage at different vertical room locations and dry bulb temperature plotted against time are shown in Figures 5.8 to 5.15. Each room orientation was measured for 24 hours in 6
days. From observations shown, it is evidence that with the usage of fan, the operative temperature swing is reduced. Moreover, the rooms located on the top floor still received the warmest operative temperature regardless of fan usage.

In H1 North rooms (Figure 5.8), higher operative temperature when fan was switched off was partially due to higher dry bulb temperature recorded than during 3 days later. However, first floor room (H1N1) show 1°C cooler during night time (i.e.: from 7pm to 7 am) than upper floors (i.e.: H1N5 and H1N9). Room H1N1 (in Block C) is located about 10m from a pond (Figure 4.13) and its vertical room location made it closer to the pond than rooms H1N5 and H1N9.

Higher operative temperature in H1 South rooms when the fan was switched on was because it was measured during warmer days compared to when the fan was switched off (Figure 5.9). Unlike room H1N1, H1 South’s first floor room (H1S1) was not located adjacent to a pond therefore no further temperature reduction was recorded.

Out of the four room orientations in H2, rooms facing the South-east especially on the first (H2SE1) and fifth floors (H2SE5) present cooler operative temperature, which do not exceed 30.5°C (Figure 5.10). This is because rooms at this location were shaded by adjacent hostel wing. In other H2 and H3 rooms, not much variation was detected between rooms at different floor levels, except for occasional temperature peaks monitored at top floor rooms (Figure 5.11 to 5.15)
Figure 5.8: $T_o$ for: (a) room with fan switched off (12 – 15 May 2007), & (b) room with fan switched on (16-18 May 2007) in H1 North
Figure 5.9: $T_o$ for: (a) room with fan switched off (19 – 21 May 2007), & (b) room with fan switched on (24 -26 May 2007) in H1 South
Figure 5.10: $T_o$ for: (a) room with fan switched off (27 – 30 May 2007), & (b) room with fan switched on (31 - 2 June 2007) in H2 South East
Figure 5.11: $T_o$ for: (a) room with fan switched off (2-5 June 2007), & (b) room with fan switched on (6-8 June 2007) in H2 South West
Figure 5.12: $T_o$ for: (a) room with fan switched off (9 - 12 June 2007), & (b) room with fan switched on (13-15 June 2007) in H2 North East
Figure 5.13: $T_o$ for: (a) room with fan switched off (17–19 June 2007), & (b) room with fan switched on (20–22 June 2007) in H2 North West
Figure 5.14: $T_o$ for: (a) room with fan switched off (23–26 June 2007), & (b) room with fan switched on (27-29 June 2007) in H3 West
Operative Temperature and Thermal Comfort Assessments

Figure 5.15: $T_o$ for: (a) room with fan switched off (30–3 July 2007), & (b) room with fan switched on (4–6 July 2007) in H3 North
Further ANOVA test was conducted to analysis the difference between operative temperature with and without fan usage (Table 5.10). All three tests show significant mean difference between those two conditions. The largest effects size is detected in H1 then followed by H3 and finally H2. Temperature differences between operative temperature with and without fan usage in H1 and H3 is 1.0°C, while in H2 is 0.5°C.

Table 5.10: Statistical summary test using ANOVA repeated measures between operative temperature with and without fan usage for H1, H2 and H3.

<table>
<thead>
<tr>
<th>Case</th>
<th>Fan usage</th>
<th>Mean</th>
<th>S.D</th>
<th>$\eta^2$</th>
<th>Significant</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1</td>
<td>Off</td>
<td>30.0</td>
<td>±1.0</td>
<td>0.49</td>
<td>$p &lt; 0.01$</td>
</tr>
<tr>
<td></td>
<td>On</td>
<td>28.9</td>
<td>±0.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H2</td>
<td>Off</td>
<td>29.7</td>
<td>±1.3</td>
<td>0.12</td>
<td>$p &lt; 0.01$</td>
</tr>
<tr>
<td></td>
<td>On</td>
<td>29.2</td>
<td>±0.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H3</td>
<td>Off</td>
<td>30.8</td>
<td>±1.3</td>
<td>0.34</td>
<td>$p &lt; 0.01$</td>
</tr>
<tr>
<td></td>
<td>On</td>
<td>29.9</td>
<td>±0.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5.2.4 Discussions and Findings: Operative Temperature Assessments

The usage of ceiling fan was observed to be efficient in controlling the operative temperature swing, but does not show much temperature reduction. The mean operative temperature monitored between rooms with and without fan usage differed significantly beyond the $p<0.01$ level (Table 5.10). In rooms that were <50m$^3$, the mean temperature difference with and without fan usage were 1.0°C for shaded rooms (H1 rooms) but are considerably lower in un-shaded rooms (H2 rooms), namely, 0.5°C. Rooms in H3 with room volume of about 100m$^3$, showed mean operative temperature difference of 1°C. Therefore, it can be suggested that naturally ventilated hostel rooms show a range indoor temperature from 29°C to 32°C.
regardless of their room size and fan usage. Temperature drop when the fan was switched on was recorded higher in shaded rooms <50m³ (i.e.: H1 rooms) and un-shaded rooms with room volume of about 100m³ (i.e.: H3 rooms).

Rooms that are shaded located at first floors (H1N1, H2SE1) are shown to be cooler in the night time than the ones at higher floors, but show almost similar temperature with one another in the daytime. H1 rooms show about 0.4°C increment from each floor level. Lesser and most of the time no temperature difference with the increase of floor levels are recorded in H2 and H3. Findings suggest that high operative temperature in hostels could not be avoided in hot humid country with a mean temperature and relative humidity of 28°C and 80%, respectively despite any vertical room location.

Operative temperatures recorded were observed to be higher in higher floor levels especially for rooms at the top floor level. This is because, these rooms received twofold of solar heat gain, namely, from the roof and window wall. Moreover, findings revealed weak level of relationship significance between room orientation and operative temperature (Figure 5.5 and 5.7). It could be suggested that rooms that are exposed to intense solar radiation in hot humid climate country experiences similar indoor temperatures regardless of orientation.

The relationship of increase in air speed to operative temperature partially indicates that the usage of ceiling fan can reduce the indoor temperature swing by improving the air movement in the measured rooms. This cooling strategy is also documented by other works to be effective in increasing thermal comfort (Mallick
However, the effect of outdoor temperature may also influence the operative temperature reading during the measurement period.

The low mean operative temperature recorded in H1 rooms is suggested to be influenced by the balcony and long roof overhang design. The projected balcony (1.5m from the window wall) protected the exterior of the window wall from solar radiation exposure, hence creating a cooler indoor temperature. Slightly higher operative temperature readings for H1 rooms located on the top floors are likely to have been caused mainly through heat gain from the roof (Table 5.4 and 5.8; Figure 5.4 and 5.5). The window walls of these particular rooms were again protected by the projected balconies. The window walls in H2 and H3 were designed without shading strategy. Furthermore, rooms on the top floors of H2 and H3 absorbed twofold of heat compared to their rooms located on the lower and middle floors due to dual heat gain sources, namely from the window walls and roof. The results mentioned are supported by finding through computer simulation from Chand et al. and Prianto and Depecker (Chand 1998; Prianto and Depecker 2002; Prianto and Depecker 2003).

Findings from Table 5.5 indicate that large volume room are more likely to display wider mean operative temperature difference between Rainy and Clear Days as seen in H3. However, there has been little change detected during either Rainy or Clear Days among the different hostels. Outdoor microclimate (Table 5.2) also show temperature difference of 1°C that could be the cause why not much operative temperature different was detected indoor among the measured rooms.
5.3 Results: Subjective thermal measurements

5.3.1 Subjective measurement details

A total of 309 subjects consisting of college aged female students living in three case study hostels participated in the survey. Valid responses for Questionnaire Component 1 and 2 are namely, 298 and 287, respectively. The summary of the questionnaire survey detail is shown in Table 5.11.

Table 5.11: Summary of questionnaire survey detail

<table>
<thead>
<tr>
<th>Details</th>
<th>H1</th>
<th>H2</th>
<th>H3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survey Duration in 2007</td>
<td>July 9 – 11 (2 days)</td>
<td>July 10 – 12 (2 days)</td>
<td>July 11 – 14 (3 days)</td>
</tr>
<tr>
<td>Number of Subjects</td>
<td>102</td>
<td>115</td>
<td>92</td>
</tr>
<tr>
<td>Valid form (Component 1: Section B to E)</td>
<td>100</td>
<td>108</td>
<td>90</td>
</tr>
<tr>
<td>Usable Forms (Component 2: Section F)</td>
<td>92</td>
<td>107</td>
<td>88</td>
</tr>
<tr>
<td>Damaged Forms (Component 1: Section B to E)</td>
<td>2</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>Damaged Forms (Component 2: Section F)</td>
<td>10</td>
<td>8</td>
<td>4</td>
</tr>
</tbody>
</table>

Figure 5.16, 5.17 and 5.18 show the sample distribution at different floor levels in H1, H2 and H3, respectively. Sample for H1 were distributed across 9 floors (Figure 5.16). More samples were collected at the upper floors starting from 6th floor and above. At that moment, most of the occupants at lower floor were not in their rooms because they were attending classes. Only 10% from the sample collected were subjects’ with less than a year staying in this particular hostel. In H2, the sample distribution was almost similar throughout all floors (Figure 5.17). The 7th floor was closed due to renovation. Unlike H1, no freshman participated in the survey in H2. Subjects were lesser in H3 (Figure 5.18) compared to the other two hostels because it was not fully occupied by students on the date the survey was conducted.
Operative Temperature and Thermal Comfort Assessments

Figure 5.16: H1 sample distribution against different level.

Figure 5.17: H2 sample distribution against different level.

Figure 5.18: H3 sample distribution against different level.
In Section A of the questionnaire, subjects’ were asked to give their age, degree type, length stayed in the particular hostel, activities when staying in their rooms and garment description. Answers to questions in this section are summarised in Table 5.12.

Table 5.12: Summary of Subjects’ Personal Detail (Answers to questions in Section A)

<table>
<thead>
<tr>
<th></th>
<th>H1</th>
<th>H2</th>
<th>H3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Age</td>
<td>29% (20 and below)</td>
<td>14% (20 and below)</td>
<td>10% (20 and below)</td>
</tr>
<tr>
<td></td>
<td>70% (21-25)</td>
<td>84% (21-25)</td>
<td>90% (21-25)</td>
</tr>
<tr>
<td></td>
<td>1% (26-30)</td>
<td>2% (26-30)</td>
<td></td>
</tr>
<tr>
<td>2. Degree type</td>
<td>Undergraduate</td>
<td>Undergraduate</td>
<td>Undergraduate</td>
</tr>
<tr>
<td>3. Length stayed</td>
<td>10% (&lt; 1 year)</td>
<td>27% (1 year)</td>
<td>9% (&lt; 1 year)</td>
</tr>
<tr>
<td></td>
<td>29% (1 year)</td>
<td>35% (2 years)</td>
<td>6% (1 year)</td>
</tr>
<tr>
<td></td>
<td>39% (2 years)</td>
<td>37% (3 years plus)</td>
<td>14% (2 years)</td>
</tr>
<tr>
<td></td>
<td>22% (3 years plus)</td>
<td></td>
<td>71% (3 years plus)</td>
</tr>
<tr>
<td>4. When there was no class, I stayed in my room….</td>
<td>85% (all day)</td>
<td>86% (all day)</td>
<td>89% (all day)</td>
</tr>
<tr>
<td></td>
<td>15% (only to sleep)</td>
<td>14% (only to sleep)</td>
<td>11% (only to sleep)</td>
</tr>
<tr>
<td>5. Activities</td>
<td>29% (Studying)</td>
<td>19% (Studying)</td>
<td>13% (Studying)</td>
</tr>
<tr>
<td></td>
<td>3% (Socialising)</td>
<td>4% (Socialising)</td>
<td>2% (Socialising)</td>
</tr>
<tr>
<td></td>
<td>8% (Relaxing)</td>
<td>9% (Relaxing)</td>
<td>12% (Relaxing)</td>
</tr>
<tr>
<td></td>
<td>2% (Sleeping)</td>
<td>2% (Sleeping)</td>
<td>2% (Sleeping)</td>
</tr>
<tr>
<td></td>
<td>58% (All the above)</td>
<td>63% (All the above)</td>
<td>70% (All the above)</td>
</tr>
<tr>
<td>6. Garment (hot days)</td>
<td>26% (type 1)</td>
<td>36% (type 1)</td>
<td>27% (type 1)</td>
</tr>
<tr>
<td></td>
<td>17% (type 2)</td>
<td>7% (type 2)</td>
<td>10% (type 2)</td>
</tr>
<tr>
<td></td>
<td>10% (type 3)</td>
<td>12% (type 3)</td>
<td>14% (type 3)</td>
</tr>
<tr>
<td></td>
<td>29% (type 4)</td>
<td>30% (type 4)</td>
<td>33% (type 4)</td>
</tr>
<tr>
<td></td>
<td>16% (type 5)</td>
<td>14% (type 5)</td>
<td>16% (type 5)</td>
</tr>
<tr>
<td></td>
<td>2% (missing)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Garment (rainy days)</td>
<td>27% (type 1)</td>
<td>33% (type 1)</td>
<td>28% (type 1)</td>
</tr>
<tr>
<td></td>
<td>29% (type 2)</td>
<td>20% (type 2)</td>
<td>20% (type 2)</td>
</tr>
<tr>
<td></td>
<td>11% (type 4)</td>
<td>4% (type 3)</td>
<td>3% (type 3)</td>
</tr>
<tr>
<td></td>
<td>1% (type 5)</td>
<td>15% (type 4)</td>
<td>17% (type 4)</td>
</tr>
<tr>
<td></td>
<td>32% (type 6)</td>
<td>1% (type 5)</td>
<td>31% (type 6)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>27% (type 6)</td>
<td></td>
</tr>
</tbody>
</table>

*Type 1: short sleeves shirt & track suit; type 2: long sleeves shirt & track suit; type 3: sleeveless shirt & sarong; type 4: short sleeves & sarong; type 5: just sarong or top & type 6: sweater-shirt & track suit.
5.3.2 Thermal comfort: rainy and clear days

Subjects were between the ages of 18 to 26 undergraduate students doing sedentary type activities. Subjects were asked to tick the types of clothes they wore during Rainy and Clear Days. Six clothing types estimated in accordance to ISO 7730 (ISO7730 2006) are shown in Table 5.13.

The summary of subjects’ daily wear clothing type for the hostels is shown in Table 5.14. It is observed that occupants change their clothing type according to the weather. The mean clo value for occupants of 0.4 in Clear Day indicating that occupants are comfortable wearing short sleeves t-shirt with sarong or shorts and underwear during that particular weather condition. Meanwhile a higher mean clo value of 0.6 is observed during Rainy Days. This suggests that occupants usually wear long sleeves t-shirt, track-suit or jeans and underwear in Rainy Days.

Table 5.13: Daily wear clothing

<table>
<thead>
<tr>
<th>Daily wear clothing</th>
<th>Clo value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1: Short sleeves t-shirt; track suit/ jeans; underwear</td>
<td>0.5</td>
</tr>
<tr>
<td>Type 2: Long sleeves t-shirt; track suit/ jeans; underwear</td>
<td>0.6</td>
</tr>
<tr>
<td>Type 3: Sleeveless t-shirt; sarong/shorts; underwear</td>
<td>0.3</td>
</tr>
<tr>
<td>Type 4: Short sleeves t-shirt; sarong/shorts; underwear</td>
<td>0.4</td>
</tr>
<tr>
<td>Type 5: Just sarong; underwear</td>
<td>0.2</td>
</tr>
<tr>
<td>Type 6: Sweater; cotton long sleeves shirt; track suit/jeans; underwear</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Table 5.14: ANOVA repeated measures on daily wear clothing during Clear Days and Rainy Days collected from the three hostels.

<table>
<thead>
<tr>
<th>Weather types</th>
<th>Mean Clo Value</th>
<th>S.D</th>
<th>$\eta^2_p$</th>
<th>Significant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear Days</td>
<td>0.4</td>
<td>±0.1</td>
<td>0.37</td>
<td>$p&lt;0.01; n=298$</td>
</tr>
<tr>
<td>Rainy Days</td>
<td>0.6</td>
<td>±0.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 5.15 shows the means estimated for Rainy and Clear Days in H1, H2 and H3. Each weather type (column of Table 5.15) show small mean difference size effects ($\eta_p^2 < 0.06$) indicating that the occupants’ individual thermal comfort votes for Rainy and Clear Days are more or less the same regardless of their hostel. However, occupants show significant mean difference beyond $p<0.01$ level with very large size effect ($\eta_p^2 > 0.14$) when asked to vote for their thermal comfort during both of the weather types (row of Table 5.15).

It can be considered that occupants in H1 found their rooms to be cooler than occupants in H2 and H3 regardless of the weather types. However, all measured rooms received quite similar operative temperature throughout the day (Table 5.8). The H1 occupants’ response in this matter can be justified through the usage of their balcony door as additional alternative to improve their indoor thermal comfort that was not available in H2 and H3 rooms. In other words, H1’s large window to wall ratio of 0.6 could have contributed to H1 occupants’ thermal perception as shown in Table 5.15.

Table 5.15: Summary of mean estimation for occupants’ thermal comfort during rainy & clear day in H1, H2 & H3 using ANOVA repeated measures. Cold (-3) to Hot (3).

<table>
<thead>
<tr>
<th>Case</th>
<th>Mean thermal comfort vote for different Weather Types</th>
<th>$\eta_p^2$ according to Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rainy day (RD)</td>
<td>Clear day (CD)</td>
</tr>
<tr>
<td>H1 (n = 100)</td>
<td>-1.5 (s.d = ±0.9)</td>
<td>0.4 (s.d = ±1.0)</td>
</tr>
<tr>
<td>H2 (n = 108)</td>
<td>-1.3 (s.d = ±0.9)</td>
<td>0.9 (s.d = ±1.0)</td>
</tr>
<tr>
<td>H3 (n = 90)</td>
<td>-1.4 (s.d = ±1.0)</td>
<td>0.5 (s.d = ±1.0)</td>
</tr>
<tr>
<td>$\eta_p^2$ according to Weather type</td>
<td>0.02 (n.s)</td>
<td>0.06 ($p&lt;0.01$)</td>
</tr>
</tbody>
</table>
The occupants in H2 however, considered that their rooms to be just slightly cooler in Rainy Day compared to Clear Day. This indicates that occupants in H2 felt that their rooms were warmer despite the weather conditions compared to occupants in other hostels. Moreover, window to wall ratio for H2 rooms were also smaller (i.e.: 0.2). Meanwhile the slightly cooler thermal response in H3 than in H2 was perhaps influenced by H3’s larger room volume and window to wall ratio of 0.4.

In order to identify occupants’ perception toward other parameters that contributed to thermal comfort, such as indoor humidity and airflow, two additional questions regarding these parameters were administered. Occupants’ perception on the humidity and airiness condition of their room during Rainy and Clear Days are display in Figures 5.19 and 5.20. Findings indicate that occupants in all three hostels are hardly sensitive to the indoor humidity level despite any weather condition (Figure 5.19); however, they are more aware of their indoor airiness condition.

Occupants felt that their room air speed increases during Rainy Day and neutral to slightly stuffy during Clear Day (Figure 5.20). This indicates that small temperature difference of 0.5°C, 0.6°C and 0.9°C for H1, H2 and H3, respectively between the two weather types (Table 5.5) with mean air speed of about 1m/s (Table 5.9) and perhaps through cross ventilation (in the case of H3 rooms) indirectly influence occupants’ response to their indoor thermal condition.
Figure 5.19: Occupants’ perception on their room’s humidity level during Rainy Day: (a), (c) & (e); Clear Day: (b), (d) & (f). Dry (-3) to Humid (3).
Figure 5.20: Occupants’ perception on their room’s airiness condition during Rainy Day: (a), (c) & (e); Clear Day: (b), (d) & (f). Draughty (-3) to Stuffy (3).
5.3.3 Thermal comfort: daytime period

Based on observations done on occupants’ thermal response during Rainy and Clear Days, the analysis expands further in investigating their response to thermal environment during the daytime periods. Table 5.16 presents thermal comfort votes in the morning (8:00 – 11:59 a.m.), afternoon (12:00 – 2:59 p.m.) and evening (3:00 – 5:59 p.m.) collected from occupants in three case study hostels.

According to daytime periods (column of Table 5.16), occupants felt that their rooms were slightly cool in the morning (point: -1.0), slightly warm in the afternoon (point: 1.0) and neutral in the evening (point: 0.0) except for occupants in H2. Occupants in H2 felt that their rooms were slightly warmer in the afternoon and evening than occupants staying in H1 and H3.

In each hostel (row of Table 5.16), occupants’ mean vote show a large size effect ($\eta^2_p > 0.14$) among the daytime periods. This indicates that occupants perceived different thermal sensation for morning, afternoon and evening which comply with the objective measurements. Objective measurements conducted in the hostels during these three periods (Table 5.6) show temperature increase of about 1.0°C from morning to afternoon. But three different effects between afternoon and evening temperature, namely, temperature decrease of 0.6°C in H1; no temperature difference in H2; and temperature increase of 0.6°C in H3. Out of the three hostels, H1 rooms are perceived to have the lowest votes in every daytime period, thus suggesting that occupants are slightly more thermally comfortable in shaded indoor condition and vice-versa.
Table 5.16: Summary of mean estimation for occupants' thermal comfort in the morning, afternoon and evening in H1, H2 & H3 using ANOVA repeated measures. Cold (-3) to Hot (3).

<table>
<thead>
<tr>
<th>Case</th>
<th>Morning (s.d = ±x)</th>
<th>Afternoon (s.d = ±y)</th>
<th>Evening (s.d = ±z)</th>
<th>$\eta_p^2$ according to Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1 (n = 100)</td>
<td>-1.0 (s.d = ±1.2)</td>
<td>0.7 (s.d = ±1.2)</td>
<td>0.1 (s.d = ±1.1)</td>
<td>0.44 ($p&lt;0.01$)</td>
</tr>
<tr>
<td>H2 (n = 108)</td>
<td>-0.6 (s.d = ±1.3)</td>
<td>1.2 (s.d = ±1.2)</td>
<td>0.7 (s.d = ±1.1)</td>
<td>0.48 ($p&lt;0.01$)</td>
</tr>
<tr>
<td>H3 (n = 90)</td>
<td>-1.0 (s.d = ±1.2)</td>
<td>0.8 (s.d = ±1.3)</td>
<td>0.2 (s.d = ±1.2)</td>
<td>0.44 ($p&lt;0.01$)</td>
</tr>
<tr>
<td>$\eta_p^2$ according to Daytime period</td>
<td>0.03 ($p&lt;0.05$)</td>
<td>0.05 ($p&lt;0.05$)</td>
<td>0.06 ($p&lt;0.01$)</td>
<td></td>
</tr>
</tbody>
</table>

5.3.4 Thermal comfort: the influence of window

In this study, it is assumed that occupants open their windows at all times. In order to provide cross examinations with earlier questions administered, occupants were asked to vote their thermal comfort sensation when the windows are opened during different weather types and other thermal physical conditions. Figure 5.21 illustrates occupants in H1, H2 and H3’s reaction toward thermal comfort in their room when the window is opened during Rainy and Clear Days. Majority of the occupants from the three hostels agree that their rooms are cool (point ‘-2’) in Rainy Day (Figure 5.21a), but experienced neither cold nor hot indoor condition (point: 0) in Clear Day (Figure 5.21b). This indicates that occupants were sensitive to the weather condition when the windows were opened.
When the window is opened, you feel... during Rainy Day

When the window is opened, you feel... during Clear Day

Figure 5.21: Thermal comfort when the window is opened in (a) rainy day; & (b) clear day. Cold (-3) to Hot (3).

When asked whether their rooms are draughty when the windows were opened most of occupants experienced frequent draughtiness (point: 1) (Figure 5.22a). However, the indoor humidity level experienced by occupants when the windows were opened is perceived as neutral (Figure 5.22b). These questions focussed on occupants' reaction toward Clear Days and not Rainy Days because the former weather type was observed to be warmer (Table 5.2) and assumed to hinder occupants' thermal comfort more than the latter one.
Operative Temperature and Thermal Comfort Assessments

Figure 5.22: Occupants' votes on: (a) room draughtiness and (b) room humidity when windows are opened. Never (-3) to Always (3).

5.3.5 Results: Optimum thermal comfort and regression models

The optimum thermal comfort, $T_{\text{conf}}$, of occupants in naturally ventilated buildings in South East Asia is estimated using equation 4.1. The average dry bulb temperatures, $T_{a\_out}$ for the month of May until July since 2002 to 2007 are 28.3°C in Petaling Jaya (H1) and 28.2°C in KLIA (H2 and H3). These months are selected to represent average dry bulb temperatures during measurement periods. Occupants’ optimum thermal comfort is thus estimated as follows:

$$T_{\text{conf}}(H1) = 17.6 + 0.31 (28.3)$$
$$= 26.4^\circ\text{C} \quad (5.1)$$

$$T_{\text{conf}}(H2) = 17.6 + 0.31 (28.2)$$
$$= 26.3^\circ\text{C} \quad (5.2)$$
90% acceptability for thermal comfort suggested is $T_{\text{comp}} \pm 3.5^\circ\text{C}$ (Zain 2007), then temperature must not exceed

\[
\begin{align*}
&= 26.4^\circ\text{C} + 3.5^\circ\text{C} \\
&= 29.9^\circ\text{C}, \text{ for H1} \\
&= 26.3^\circ\text{C} + 3.5^\circ\text{C} \\
&= 29.8^\circ\text{C}, \text{ for H2 and H3}
\end{align*}
\]

(5.3)

(5.4)

Figure 5.23 shows the regression of occupants' thermal comfort votes for both rainy and clear days on operative temperature in H1 (Figure 5.23a) and H2 (Figure 5.23b). Rainy and clear days regressed on operative temperature in H1 and H2 show significant Pearson linear correlation beyond $p<0.001$: $r = 0.369$ and $r = 0.325$, respectively. The relationship indicated in figure 6 are not strong in H1, $R^2 = 0.136$ and H2, $R^2 = 0.106$. In H1, the slope of regression line is 0.421/°C, which means up to 33.3°C variation of operative temperature can cause the thermal comfort vote to vary by 1. In H2, the slope of regression line is 0.668/°C, where up to 30.1°C variation of operative temperature causes the thermal comfort vote to vary by 1. The regression analysis of mean thermal comfort vote during rainy and clear days in H1 and H2 give thermal neutral temperatures of 30.9°C and 28.6°C, respectively.

Results from these three calculations differed from each other. However, the optimum thermal comfort model with 90% acceptability provided closer mean neutral temperature (29.9°C in H1 and 29.8°C in H2) with the mean neutral temperature calculated from linear regression model relating occupants' thermal comfort vote with operative temperature (30.9°C in H1 and 28.6°C in H2).
Figure 5.23: Regression of occupants' thermal comfort vote for rainy day (RD) and clear day (CD) against operative temperature in: (a) H1; (b) H2 and (c) H3.

(a) $y = -13.02 + 0.421x; r = 0.369; p<0.001.$

(b) $y = -19.12 + 0.668x; r = 0.325; p<0.001$

(c) $r = 0.005; \text{not significant.}$
5.3.6 Discussions and Findings: Thermal Comfort Assessments

Findings from the thermal comfort assessments can be explained through the ‘Adaptive Theory’ which suggests that people are not passively receptive of their thermal environment (De Dear and Brager 2002; Zhang 2007). They adapt to their environment but may feel discomfort when change occurs. This can be linked to why occupants are neutrally comfortable in the current operative temperature and response whenever peak temperature changes. In this investigation, the peaks are determined through ‘rainy and clear days’ weather condition. Feedbacks from occupants showed that draughtier conditions experienced during the rainy days helped to cool down their room despite the fairly low level of air speed evidenced.

The level of thermal tolerance shown could be related to the occupants’ action in lessening the thermoregulatory constraints. Findings from the clothing type assessment suggest that different thermoregulatory actions can be related to the weather types. Occupants acclimatised according to their indoor thermal condition by modifying their clothing type. Occupants tend to put on lower clo value of 0.4 during warmer and dryer days (Clear Days) and slightly higher clo value of 0.6 during cooler and wetter days (Rainy Days).

Moreover, findings showed that larger window opening size that is shaded can increase the level of thermal comfort. Despite the low correlation value obtained, the regression model of occupants’ thermal comfort vote against typical indoor operative temperature of rooms showed that occupants living in shaded rooms demonstrate higher indoor temperature tolerance compared to those living in un-shaded rooms.
Summary

Findings in this chapter suggested that shaded rooms in H1 were more thermally desirable to occupants of typical multi-storey hostels in Malaysia based on both thermal objective and subjective measurements. However in terms of daylighting, rooms in H1 are assumed to have lesser natural lighting intake than un-shaded rooms like H2 and H3. Chapter 6 is dedicated in assessing daylight ratio, luminance of window and visual comfort recorded from the selected hostels.
CHAPTER 6

DAYLIGHT RATIO, LUMINANCE OF WINDOW AND VISUAL COMFORT ASSESSMENTS

6.1 Introduction

Investigations on visual condition in the selected hostels are discussed based on the following objectives:

i. To comprehensively measure the indoor and outdoor illumination level of selected hostels by means of external illumination, daylight ratio and luminance of window.

ii. To assess subjective visual comfort experienced by occupants via questionnaire survey.

6.2 Results: Objective visual measurements

6.2.1 External and internal horizontal illumination

External horizontal illumination and internal illumination data were used to estimate daylight ratio available in measured rooms. Table 6.1 provides a summary of the external illumination collected during measurement periods. In overall, the mean external horizontal illumination measured was about 50 Klx.
Table 6.1: Summary of external horizontal illumination during measurement period.

<table>
<thead>
<tr>
<th></th>
<th>H1N</th>
<th>H1S</th>
<th>H2SE</th>
<th>H2SW</th>
<th>H2NE</th>
<th>H2NW</th>
<th>H3W</th>
<th>H3N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>48</td>
<td>52</td>
<td>48</td>
<td>52</td>
<td>51</td>
<td>43</td>
<td>48</td>
<td>54</td>
</tr>
<tr>
<td>Min.</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>10</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Max.</td>
<td>115</td>
<td>115</td>
<td>109</td>
<td>109</td>
<td>108</td>
<td>105</td>
<td>104</td>
<td>103</td>
</tr>
<tr>
<td>S. D (±)</td>
<td>35</td>
<td>38</td>
<td>34</td>
<td>39</td>
<td>31</td>
<td>25</td>
<td>27</td>
<td>29</td>
</tr>
</tbody>
</table>

Indication of Rainy and Clear Days is shown in Table 5.1. External horizontal illumination in Clear Day is about 6 Klx lower than Rainy Day (Table 6.2). The difference in sky illumination shown is a result of the clouds influence as the albedo in absorbing and reflecting of solar radiation. Overcast sky is brighter than clear sky because it receives diffused light through the maximum brightness from the sun. During clear sky, the zenith is not the brightest area that resulted in lower illumination level than during overcast sky (Egan 2002; Heerwagen 2004). Therefore this resulted in higher external horizontal illumination during Rainy Day than Clear Day.

Table 6.2: ANOVA repeated measures of External illumination during rainy (RD) and clear day (CD) in H1, H2 and H3.

<table>
<thead>
<tr>
<th>Day</th>
<th>Mean</th>
<th>S.D</th>
<th>Partial eta Squared</th>
<th>Significant</th>
</tr>
</thead>
<tbody>
<tr>
<td>E_{in}, Klx</td>
<td>CD</td>
<td>43</td>
<td>±34</td>
<td>0.14</td>
</tr>
<tr>
<td></td>
<td>RD</td>
<td>57</td>
<td>±31</td>
<td>p&lt;0.01</td>
</tr>
</tbody>
</table>

Internal illumination was measured in 24 naturally lit rooms in typical multi-storey hostels. Table 6.3 shows the summary of result measured at three different floor levels located at first, fifth and top (7th, 9th, or 10th) floors in H1, H2, and H3.
Internal horizontal illumination distribution in overall was lower and more constant at the higher floors, i.e.: 9\textsuperscript{th} and 10\textsuperscript{th} floor compared to room located seventh floor and below. North-West oriented rooms in H2 display the highest mean illumination of 1880 Klx, 2007 Klx and 1954 Klx for first, fifth and seventh floor rooms, respectively. Meanwhile the lowest mean illumination was measured in H1 South rooms, namely, 336 Klx, 405 Klx and 137 Klx for first, fifth and ninth floor rooms, respectively.

These findings indicate that rooms facing north-west and un-shaded received high amount of illumination transmittance, despite a relatively low mean external horizontal illumination level recorded (Table 6.1). Moreover, rooms facing south and shaded received low illumination levels even though the external horizontal illumination measured was relatively high (Table 6.1).
Table 6.3: Internal horizontal illumination level at three room levels on the first, fifth and top floors of H1, H2 and H3.

<table>
<thead>
<tr>
<th>Orientation</th>
<th>Internal horizontal illumination, lux</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>H1</td>
</tr>
<tr>
<td></td>
<td>1st flr</td>
</tr>
<tr>
<td>North</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>447</td>
</tr>
<tr>
<td>25th perc.</td>
<td>137</td>
</tr>
<tr>
<td>75th perc.</td>
<td>690</td>
</tr>
<tr>
<td>S.D</td>
<td>±306</td>
</tr>
<tr>
<td>South</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>336</td>
</tr>
<tr>
<td>25th perc.</td>
<td>233</td>
</tr>
<tr>
<td>75th perc.</td>
<td>402</td>
</tr>
<tr>
<td>S.D</td>
<td>±191</td>
</tr>
<tr>
<td>West</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>1442</td>
</tr>
<tr>
<td>25th perc.</td>
<td>945</td>
</tr>
<tr>
<td>75th perc.</td>
<td>1935</td>
</tr>
<tr>
<td>S.D</td>
<td>±664</td>
</tr>
<tr>
<td>South-East</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>617</td>
</tr>
<tr>
<td>25th perc.</td>
<td>424</td>
</tr>
<tr>
<td>75th perc.</td>
<td>764</td>
</tr>
<tr>
<td>S.D</td>
<td>±289</td>
</tr>
<tr>
<td>South-West</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>641</td>
</tr>
<tr>
<td>25th perc.</td>
<td>259</td>
</tr>
<tr>
<td>75th perc.</td>
<td>1004</td>
</tr>
<tr>
<td>S.D</td>
<td>±413</td>
</tr>
<tr>
<td>North-West</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>1880</td>
</tr>
<tr>
<td>25th perc.</td>
<td>813</td>
</tr>
<tr>
<td>75th perc.</td>
<td>1891</td>
</tr>
<tr>
<td>S.D</td>
<td>±3045</td>
</tr>
<tr>
<td>North-east</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>1236</td>
</tr>
<tr>
<td>25th perc.</td>
<td>792</td>
</tr>
<tr>
<td>75th perc.</td>
<td>1657</td>
</tr>
<tr>
<td>S.D</td>
<td>±646</td>
</tr>
</tbody>
</table>

Note: '-' = Not available
6.2.2 Daylight Ratio measurements

Daylight ratio for the measured rooms was calculated based on Equation 2.9. Table 6.4 shows the statistical summary for Daylight Ratio at three different vertical room locations in H1, H2 and H3. In sum, most of the measured rooms show daylight ratios that were in compliance the minimum daylight factor provided by CIBSE (CIBSE 1987), namely above 0.5 % for a multi-purpose room.

On the other hand, rooms in H2, especially the ones facing North-west and North-east were over lit, namely above 2 % of daylight ratio, which exceed the average daylight factor for domestic application (CIBSE 1987). The daylight ratio recorded for these H2 rooms were higher than rooms in H3 that were also larger in volume. In order to understand the daylighting behaviour of the measured rooms, additional tests on the daylight ratio during different weather types and daytime periods were conducted.
### Table 6.4: Daylight ratio (%) level in measured rooms on the first, fifth and top floors of H1, H2 and H3.

<table>
<thead>
<tr>
<th>Orientation</th>
<th>Daylight Ratio, %</th>
<th>1\textsuperscript{st} flr</th>
<th>5\textsuperscript{th} flr</th>
<th>9\textsuperscript{th} flr</th>
<th>1\textsuperscript{st} flr</th>
<th>5\textsuperscript{th} flr</th>
<th>7\textsuperscript{th} flr</th>
<th>1\textsuperscript{st} flr</th>
<th>5\textsuperscript{th} flr</th>
<th>10\textsuperscript{th} flr</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Mean</td>
<td>1.2</td>
<td>1.3</td>
<td>0.5</td>
<td>-</td>
<td>-</td>
<td>3.9</td>
<td>4.4</td>
<td>2.8</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>25\textsuperscript{th} perc.</td>
<td>0.6</td>
<td>0.8</td>
<td>0.3</td>
<td>-</td>
<td>-</td>
<td>2.5</td>
<td>2.6</td>
<td>1.8</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>75\textsuperscript{th} perc.</td>
<td>1.5</td>
<td>1.6</td>
<td>0.5</td>
<td>-</td>
<td>-</td>
<td>4.7</td>
<td>4.8</td>
<td>2.9</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>S.D</td>
<td>±0.8</td>
<td>±0.8</td>
<td>±0.3</td>
<td>-</td>
<td>-</td>
<td>±1.7</td>
<td>±2.5</td>
<td>±1.4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>South Mean</td>
<td>1.0</td>
<td>1.4</td>
<td>0.5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>25\textsuperscript{th} perc.</td>
<td>0.4</td>
<td>0.6</td>
<td>0.2</td>
<td>-</td>
<td>-</td>
<td>2.3</td>
<td>2.2</td>
<td>1.7</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>75\textsuperscript{th} perc.</td>
<td>1.5</td>
<td>1.7</td>
<td>0.5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>S.D</td>
<td>±0.6</td>
<td>±1.3</td>
<td>±0.3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>West Mean</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3.5</td>
<td>3.3</td>
<td>2.3</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>25\textsuperscript{th} perc.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2.3</td>
<td>2.2</td>
<td>1.7</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>75\textsuperscript{th} perc.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4.4</td>
<td>4.1</td>
<td>2.7</td>
<td>-</td>
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</tr>
<tr>
<td>S.D</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>±1.5</td>
<td>±1.3</td>
<td>±1.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>South-East Mean</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.7</td>
<td>2.3</td>
<td>2.7</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>25\textsuperscript{th} perc.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.1</td>
<td>1.3</td>
<td>1.3</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>75\textsuperscript{th} perc.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2.3</td>
<td>2.8</td>
<td>3.8</td>
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<tr>
<td>S.D</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>±0.8</td>
<td>±1.3</td>
<td>±1.5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>South-West Mean</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.9</td>
<td>2.1</td>
<td>2.2</td>
<td>-</td>
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</tr>
<tr>
<td>25\textsuperscript{th} perc.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.8</td>
<td>0.9</td>
<td>1.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>75\textsuperscript{th} perc.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2.4</td>
<td>3.0</td>
<td>3.1</td>
<td>-</td>
<td>-</td>
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<tr>
<td>S.D</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>±1.8</td>
<td>±1.8</td>
<td>±1.9</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>North-West Mean</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4.7</td>
<td>4.9</td>
<td>4.7</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>25\textsuperscript{th} perc.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2.5</td>
<td>2.5</td>
<td>2.7</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>75\textsuperscript{th} perc.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4.4</td>
<td>4.4</td>
<td>4.4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>S.D</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>±7.0</td>
<td>±7.0</td>
<td>±5.5</td>
<td>-</td>
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<tr>
<td>North-east Mean</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3.0</td>
<td>3.6</td>
<td>3.8</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>25\textsuperscript{th} perc.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.5</td>
<td>1.8</td>
<td>2.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>75\textsuperscript{th} perc.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4.1</td>
<td>4.9</td>
<td>5.1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>S.D</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>±1.5</td>
<td>±1.9</td>
<td>±2.2</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Note: '-' = Not available

An observation of mean Daylight Ratio at different vertical room location is shown in Figure 6.1. Lower and middle floor rooms are located at 3m and 15m above ground, respectively. Meanwhile rooms on top floors of H1, H2 and H3 are measured at 27m, 21m and 30m above ground, respectively. As expected, shaded rooms in H1 obtained the lowest Daylight Ratio than un-shaded rooms in H2 and H3.
In terms of daylight ratio pattern, it can be observed that daylight ratio increases up until a certain altitude, namely 21m (i.e.: rooms on top floor of H2), but decreases as the vertical room location increases further (i.e.: rooms on top floor of H1 and H3). Obstructions such as trees and other low-rise structure were not available at 15m above ground thus enabling daylight level to increase in rooms at this particular floor level. The reduction of daylight ratio in rooms above 21m above ground could have been influenced by lack of incidental daylight from other reflective sources.

Figure 6.1: Mean Daylight Ratio at different vertical room locations in H1, H2 and H3.

Figure 6.2 shows the daylight ratio collected at different room orientations in H1, H2 and H3. Each room orientation has three measured rooms. As expected, shaded rooms received the lowest Daylight Ratio than un-shaded rooms (Figure 6.2a). North-west oriented un-shaded rooms in H2 are exposed to the highest daylight ratio,
Despite its relatively low external horizontal illumination (Table 6.1). In H3, North-facing rooms received more daylight than west facing rooms because the former room orientation was exposed to more external horizontal illumination than the latter room orientation (Table 6.1).

![Figure 6.2: Mean Daylight Ratio at different room orientation in: (a) H1; (b) H2 and (c) H3.](image)

In further examining the effects of shading strategy to daylight ratio during two common weather types in Malaysia, an ANOVA repeated measures are conducted. Table 6.5 summaries the daylight ratio received during Rainy and Clear Days in the case study hotels. The daylight ratio during Rainy and Clear Days received by H1, H2 and H3 show very strong significance difference \((p<0.01)\) with larger size effects of above 0.14 (column of Table 6.5). Mean daylight ratios recorded in Clear Day differed wider than in Rainy Day. Daylight level received in rooms ascended from H1, followed by H2 and finally H3 for each weather type. This is because H1 rooms are shaded while the other rooms are not. H3 rooms received more daylight ratio than H2 rooms partially because the floor reflectance factor in the former hostel was higher, namely, 0.6 (Table 4.10).
Moreover, very small mean differences are detected between Rainy and Clear Days in H1, H2 and H3 (row of Table 6.5). This suggests that weather has no clear influence over the daylight level of a room. Therefore, it can be partially concluded that the window to wall ratio, shading ratio and indoor surface reflectance factor were more important in controlling daylight ratio compared to weather conditions. In terms of daylighting condition in rooms, despite receiving the lowest daylight ratio compared to other rooms, the mean daylight ratio for rooms in H1 during Rainy and Clear Days were above the minimum daylight factor recommended by CIBSE (CIBSE 1987), thus indicating that shaded rooms in H1 succeeded in providing sufficient daylighting regardless of weather condition.

Table 6.5: ANOVA repeated measures of daylight ratio during Rainy and Clear Days in H1, H2 and H3.

<table>
<thead>
<tr>
<th>Case</th>
<th>Rainy day (RD)</th>
<th>Clear day (CD)</th>
<th>$\eta^2_p$ according to Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1</td>
<td>1.1 (s.d = ±1.0)</td>
<td>0.8 (s.d = ±0.7)</td>
<td>0.06 ($p&lt;0.01$)</td>
</tr>
<tr>
<td>H2</td>
<td>2.2 (s.d = ±1.8)</td>
<td>2.3 (s.d = ±1.4)</td>
<td>0.00 (n.s)</td>
</tr>
<tr>
<td>H3</td>
<td>3.1 (s.d = ±1.3)</td>
<td>3.4 (s.d = ±1.7)</td>
<td>0.02 (n.s)</td>
</tr>
<tr>
<td>$\eta^2_p$ according to Weather type</td>
<td>0.34 ($p&lt;0.01$)</td>
<td>0.51 ($p&lt;0.01$)</td>
<td></td>
</tr>
</tbody>
</table>

Furthermore, daylight ratio received in rooms was breakdown according to three different daytime periods, namely, morning (8:00 am to 11:59 am), afternoon (12:00 pm to 2:59 pm) and evening (3:00 pm to 5:59 pm). Table 6.6 presents the mean daylight ratios for rooms in H1, H2 and H3 during those periods. In each daytime period (column of Table 6.6), mean daylight ratio recorded show significant mean difference beyond $p<0.01$ level with large size effects ($\eta^2_p > 0.14$) among the hostels. As expected, the level of daylight ratio mean difference for each period was
widest in the morning, and descends as the day progresses, based on the decreasing external horizontal illumination in the evening. In this test, it still shows that rooms in H1 presents the least (but sufficient daylight ratio) compared to the other rooms during all three daytime periods.

In each case study hostel (row of Table 6.6), medium size effects ($\eta^2_p < 0.14$) of mean differences are detected in H1 and H2 rooms, while H3 rooms show an even smaller size effect ($\eta^2_p < 0.06$). This suggests that the daylight ratio in each case from 8:00 am until 5:59 pm differed significantly, but with very small daylight ratio variation. Higher daylight ratio was available in the evening, which resulted from decrease in the denominator (i.e.: external illumination) in the estimation of the daylight ratio model (Equation 2.9). Therefore it is somewhat evidenced that despite diurnal changes observed throughout the daytime, the daylight ratio difference could have been also influenced by the window to wall ratio, shading ratio and indoor surface reflectance factor.

Table 6.6: ANOVA repeated measures of daylight ratio in the morning (8:00 am to 11:59 am), afternoon (12:00 pm to 2:59 pm) and evening (3:00 pm to 5:59pm) in H1, H2 & H3.

<table>
<thead>
<tr>
<th>Case</th>
<th>Mean Daylight Ratio (%) for different Daytime period</th>
<th>$\eta^2_p$ according to Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Morning</td>
<td>Afternoon</td>
</tr>
<tr>
<td>H1</td>
<td>1.0 (s.d = ±0.7)</td>
<td>0.7 (s.d = ±0.6)</td>
</tr>
<tr>
<td>H2</td>
<td>2.0 (s.d = ±1.2)</td>
<td>2.2 (s.d = ±1.5)</td>
</tr>
<tr>
<td>H3</td>
<td>3.3 (s.d = ±1.6)</td>
<td>3.1 (s.d = ±2.0)</td>
</tr>
<tr>
<td></td>
<td>$\eta^2_p$ according to Daytime period</td>
<td>0.47 ($p &lt; 0.01$)</td>
</tr>
</tbody>
</table>

Chapter 6, page 10
6.2.3 Hourly Luminance of window

Table 6.7 and Figure 6.3 present the luminance of window measured in 24 naturally lit hostels rooms in H1, H2 and H3. In overall, the luminance level increases in accordance to the vertical room location.

Table 6.7: Luminance of window (cd/m²) level at three room levels on the first, fifth and top floors of H1, H2 and H3.

<table>
<thead>
<tr>
<th>Orientation</th>
<th>H1</th>
<th>H2</th>
<th>H3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1st flr</td>
<td>5th flr</td>
<td>9th flr</td>
</tr>
<tr>
<td>North</td>
<td>Mean 1183</td>
<td>1610 3061</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>S.D ±686</td>
<td>981 1655</td>
<td>-</td>
</tr>
<tr>
<td>South</td>
<td>Mean 409</td>
<td>1653 2036</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>S.D ±209</td>
<td>726 903</td>
<td>-</td>
</tr>
<tr>
<td>West</td>
<td>Mean -</td>
<td>- - -</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>S.D ± -</td>
<td>- - -</td>
<td>-</td>
</tr>
<tr>
<td>South-East</td>
<td>Mean -</td>
<td>- - -</td>
<td>443 2307</td>
</tr>
<tr>
<td></td>
<td>S.D ± -</td>
<td>- - -</td>
<td>175 1008</td>
</tr>
<tr>
<td>South-West</td>
<td>Mean -</td>
<td>- - -</td>
<td>1367 3682</td>
</tr>
<tr>
<td></td>
<td>S.D ± -</td>
<td>- - -</td>
<td>846 1613</td>
</tr>
<tr>
<td>North-West</td>
<td>Mean -</td>
<td>- - -</td>
<td>913 1210</td>
</tr>
<tr>
<td></td>
<td>S.D ± -</td>
<td>- - -</td>
<td>542 649</td>
</tr>
<tr>
<td>North-east</td>
<td>Mean -</td>
<td>- - -</td>
<td>853 2279</td>
</tr>
<tr>
<td></td>
<td>S.D ± -</td>
<td>- - -</td>
<td>525 908</td>
</tr>
</tbody>
</table>

Note: ‘-’ = Not available
Cross-examinations between Figures 6.2 and 6.4 found that luminance level has an inverse relationship with daylight ratio as observed in H1 and H2. However, in H3, luminance level increases in accordance to daylight ratio. The condition in H3 rooms could be partially influenced by window to wall ratio (WWR). Higher WWR of 0.4 in H3 rooms than in H2 (i.e.: WWR = 0.2) enable more luminance of window to be available in the former hostel rooms.
Mean luminance from the window during Rainy and Clear Day is shown in Table 6.8. Although differed significantly beyond at least $p<0.05$ level, the means are not widely distributed in among the weather types (column of Table 6.8) and case study hostels (row of Table 6.8). This indicates that neither fenestration features (i.e.: window to wall and shading ratio) nor weather types show clear influence towards the luminance measured.

Table 6.8: ANOVA repeated measures of luminance of window during Rainy and Clear Days in H1, H2 and H3.

<table>
<thead>
<tr>
<th>Case</th>
<th>Mean Luminance of window (cd/m²) for different weather types</th>
<th>$\eta^2_p$ according to Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rainy day (RD)</td>
<td>Clear Day (CD)</td>
</tr>
<tr>
<td>H1</td>
<td>1836 (s.d. = ±1183)</td>
<td>1482 (s.d. = ±1289)</td>
</tr>
<tr>
<td>H2</td>
<td>2150 (s.d. = ±1520)</td>
<td>2565 (s.d. = ±1809)</td>
</tr>
<tr>
<td>H3</td>
<td>2728 (s.d. = ±2276)</td>
<td>2146 (s.d. = ±2487)</td>
</tr>
<tr>
<td>$\eta^2_p$ according to Weather type</td>
<td>0.16 ($p&lt;0.01$)</td>
<td>0.07 ($p&lt;0.05$)</td>
</tr>
</tbody>
</table>

Investigation on luminance of window in the morning, afternoon and evening is summarized in Table 6.9. It can be observed that the highest level of luminance is measured in the afternoon for all three hostels.
Table 6.9: ANOVA repeated measures of luminance of window in the morning (8:00 am to 11:59 am), afternoon (12:00 pm to 2:59 pm) and evening (3:00 pm to 5:59pm) in H1, H2 & H3.

<table>
<thead>
<tr>
<th>Case</th>
<th>Morning (s.d = ±1329)</th>
<th>Afternoon (s.d = ±1278)</th>
<th>Evening (s.d = ±691)</th>
<th>$\eta^2$ according to Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1</td>
<td>1852</td>
<td>2263</td>
<td>763</td>
<td>0.31 (p&lt;0.01)</td>
</tr>
<tr>
<td>H2</td>
<td>2381 (s.d = ±1620)</td>
<td>2564 (s.d = ±1623)</td>
<td>1593 (s.d = ±1266)</td>
<td>0.12 (p&lt;0.01)</td>
</tr>
<tr>
<td>H3</td>
<td>1470 (s.d = ±1387)</td>
<td>3032 (s.d = ±2179)</td>
<td>2873 (s.d = ±2586)</td>
<td>0.21 (p&lt;0.01)</td>
</tr>
</tbody>
</table>

6.2.4 Discussions and findings: Daylight Ratio and Luminance of Window Assessments

Daylight ratio measured although rises in accordance to floor level, but later show deterioration once reaching over 27m above ground (Figure 6.1). This could be resulted from lack of incident daylighting source, which increases daylight ratio in opposite building, however not many literature support this notion (Tsangrassoulis 1999; Brotas 2002).

Throughout the assessments, rooms in H1 with window to wall ratio of 0.6 and shading ratio from 0.9 (i.e.: via projected balcony) to 1.6 (i.e.: long roof overhang) provided adequate daylight ratio as recommended by CIBSE (CIBSE 1987) for small size hostels room of 45m$^3$. Rooms in H2 however received excessive daylight ratio especially the ones facing north-east and north-west. This partially suggest that small rooms (i.e: 48m$^3$) with WWR of 0.2 and un-shaded tend to be very bright. It is also suggested that because the width and depth of rooms in H2 are almost similar, could be the cause of the high daylight level detected which is also in agreements with finding by Ghisi and Tinker (Ghisi and Tinker 2005).
6.3 Results: Subjective visual comfort survey

298 female college-aged students staying in H1, H2 and H3 took part in this survey.

6.3.1 Visual comfort: rainy and clear days

Table 6.10 summarizes the visual comfort votes on Rainy and Clear Days collected from occupants in H1, H2 and H3. Occupants participated in the subjective survey in H1, H2 and H3 were 100, 108, and 90 persons, respectively. In reference to results presented in row of Table 6.10, it seems that occupants in H1 were the least sensitive to their visual comfort during rainy and clear days. Meanwhile, based on their wide visual comfort response during rainy and clear days, indicated that rooms in H3 were quite bright during the clear days and can be neutral (neither bright nor dark) during the rainy days.

In other words, this also indicates that occupants’ visual comfort votes regardless of window size, and room volume (column of Table 6.10), are strongly influenced by the weather condition. Therefore, it can be suggested that an occupant’s visual comfort response follows the physical measurement.

Table 6.10: Summary of mean estimation for occupants’ visual comfort during rainy & clear day in H1, H2 & H3 using ANOVA repeated measures. Dark (-3) to Bright (3).

<table>
<thead>
<tr>
<th>Case</th>
<th>Mean visual comfort vote for different Weather Types</th>
<th>( \eta^2_p ) according to Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rainy day (RD)</td>
<td>Clear day (CD)</td>
</tr>
<tr>
<td>H1 (n = 100)</td>
<td>-0.4 (s.d = ±1.4)</td>
<td>1.3 (s.d = ±1.4)</td>
</tr>
<tr>
<td>H2 (n = 108)</td>
<td>-0.3 (s.d = ±1.3)</td>
<td>1.4 (s.d = ±1.3)</td>
</tr>
<tr>
<td>H3 (n = 90)</td>
<td>-0.4 (s.d = ±1.4)</td>
<td>1.5 (s.d = ±1.3)</td>
</tr>
<tr>
<td>( \eta^2_p ) according to Weather type</td>
<td>0.0 (n.s)</td>
<td>0.0 (n.s)</td>
</tr>
</tbody>
</table>
Occupants were further asked regarding the adequacy of daylighting in illuminating their rooms during Rainy and Clear Days. Figure 6.5 illustrates the vote distribution sampled from H1, H2 and H3. In H1, 31% of occupants expressed that the daylighting condition in their rooms during Rainy Day were quite inadequate (Figure 6.5a). Their mean votes shifted from -0.6 to 1.2 when asked regarding their daylighting availability in Clear Day (Figure 6.5b). The vote distributions in H3 (Figures 6.5e and 6.5f) show quite a resemblance to the one sampled in H1 in both Rainy and Clear Days.

However, occupants in H2 experienced high levels of daylighting availability in both Rainy and Clear Days (Figures 6.5c and 6.5d). From these vote distributions, it can be concluded that rooms in H2 are brightly lit through daylighting despite any weather conditions. Meanwhile rooms in H1 are perceived to be the dimmest in both Rainy and Clear Days.
Figure 6.5: Enough daylighting in Rainy Day: (a), (c) & (e); Clear day: (b), (d) & (f). Inadequate (-3) to Adequate (3).
Figure 6.6 represents occupants’ satisfaction votes with the daylighting condition in their rooms. As expected, occupants in H1 were least satisfied with the daylighting condition with mean vote of 0.9. The highest level of satisfaction was shown in H3. Findings confirmed that rooms in H1 were not only dimmer (refer to Table 6.6) but also had the least visual comfort vote compared to other rooms.

![Graphs showing satisfaction votes for different rooms](image)

Figure 6.6: Satisfy with daylighting performance in room for: (a) H1; (b) H2 & (c) H3. Dissatisfied (-3) to Satisfied (3).
6.3.2 Visual comfort: daytime period

Summary of mean for visual comfort votes in the morning (8:00 – 11:59 a.m.), afternoon (12:00 – 2:59 p.m.) and evening (3:00 – 5:59 p.m.) collected from occupants in three case study hostels is shown in Table 6.11. Out of the three daytime periods, mean visual comfort differed significantly beyond $p<0.01$ only during the afternoon (column of Table 6.11). This show that occupants were more aware of the impact of glare in the afternoon compare to in the morning and evening and despite any fenestration features. This was because large floods of sunlight (as observed in H2 and H3) was usually evidenced in the floor of their rooms in the afternoon and was considered to cause not only glare discomforts but also heat gain.

Occupants' votes in Table 6.11 also reveal their pattern of expectation towards the daylighting condition from morning to evening (row of Table 6.11). It shows that occupants, regardless of their hostel, express similar visual comfort vote for morning and evening, which usually fall between point 'neutral' and 'slightly lit'. In the afternoon, all occupants voted that their rooms were usually quite bright (point: 1.5 to 2.0).

Table 6.11: Summary of mean estimation for occupants' visual comfort in the morning, afternoon and evening in H1, H2 & H3. Dark (-3) to Bright (3).

<table>
<thead>
<tr>
<th>Case</th>
<th>Mean visual comfort vote for different Daytime period</th>
<th>$\eta^2_p$ according to Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Morning; Afternoon; Evening</td>
<td></td>
</tr>
<tr>
<td>H1 (n = 100)</td>
<td>0.4 (s.d = ±1.5); 1.5 (s.d = ±1.4); 0.4 (s.d = ±1.4)</td>
<td>0.25 ($p&lt;0.01$)</td>
</tr>
<tr>
<td>H2 (n = 108)</td>
<td>0.7 (s.d = ±1.7); 1.9 (s.d = ±1.2); 0.7 (s.d = ±1.5)</td>
<td>0.24 ($p&lt;0.01$)</td>
</tr>
<tr>
<td>H3 (n = 90)</td>
<td>0.9 (s.d = ±1.5); 2.0 (s.d = ±1.1); 0.5 (s.d = ±1.6)</td>
<td>0.33 ($p&lt;0.01$)</td>
</tr>
<tr>
<td>$\eta^2_p$ according to Daytime period</td>
<td>0.03 (n.s); 0.05 ($p&lt;0.01$); 0.01 (n.s)</td>
<td></td>
</tr>
</tbody>
</table>
6.3.3 Visual comfort: window function

Results from investigation on whether occupants were in content with the size of their window’s aperture in allowing daylighting are illustrated in Figures 6.7a to 6.7c. Mean votes ascended from H1, H2 and H3 with means of 1.0; 1.6 and 1.7, respectively. This indicates that occupants in overall show satisfactory agreement that the window allow adequate daylighting into their room. However, a few occupants in H1 show less satisfactory vote, because their rooms were dimmer than the other hostel rooms. 73% and 78% of occupants in H2 and H3 respectively voted above the neutral point (point = 0), however only 60% of occupants in H1 fall into this category.
To cross-examine whether the daylighting performance in hostel rooms were not deprived by curtain usage throughout the day, occupants were asked whether or not they pull the curtain during Clear Day. It was assumed that occupants perceived the daylight transmittance to be higher in Clear Day compared to Rainy Day, thus provide better daylighting source compared to during the latter weather condition. In other words, occupants were most likely to switch on artificial lighting during Rainy Day than during Clear Day. Occupants' vote regarding this matter is shown in Figure 6.8. The least vote with mean value of -0.1 was found in H1, which indicates that its occupants hardly pull their curtain during Clear Day. On the contrary, the average of occupants in H2 and H3 voted that they quite regularly (point: 1.0) pull the curtain on Clear Day.

The responses shown could be related to daylight ratio and luminance availability during Clear Days (Tables 6.5 and 6.8). Votes in H1 suggested that its occupants' reaction in rarely using the curtain were because they perceived their
rooms to receive low daylight and luminance levels; hence, more daylighting was expected. While occupants in H2 and H3 perceived the opposite out of the indoor visual condition of their rooms.

Figure 6.8: Do you pull the curtain on a Clear Day? (a) H1; (b) H2 & (c) H3 Never (-3) to Always (3).
Correlation between occupant’s curtain usage vote and glare tolerance vote during Clear Day is shown in Table 6.12. From the observation, it shows that occupants staying in H2 rooms have the highest correlation value, i.e. beyond $p<0.01$ level, than the other two hostels. The significant relationship was perhaps being influenced by the fact that rooms in H2 had higher glare availability (point: 0.7) than in H1 and H3. Therefore, it can be suggested that the more intense the glare condition indoors, the higher the curtain usage will be.

However, the usage of artificial lights not was favored even though most of the occupants prefer to pull their window curtain during Clear Day. Occupants from all three hostels expressed that they rarely switch on the artificial lights during Clear Day (Figure 6.9 and Table 6.13). Votes from H1 occupants verify that even though their rooms were perceived to be dimmer compare to in H2 and H3 in Clear Day (Table 6.13), occupants here were satisfied with the visual condition in their rooms. Even though, strong negative correlation value is identified, but not much variation of mean artificial lighting usage is detected among the three hostels.
Do you switched on the lights on Clear Day? (H1)

Do you switched on the lights on Clear Day? (H2)

Do you switched on the lights on Clear Day? (H3)

Figure 6.9: Do you switched on the lights on Clear Day? (a) H1; (b) H2 & (c) H3. Never (-3) to Always (3)

Table 6.13: Correlation between occupant’s artificial lighting usage with daylight availability during clear day (CD).

<table>
<thead>
<tr>
<th>Case</th>
<th>Mean (s.d)</th>
<th>Pearson Correlation (Sig.:2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1 (n = 100)</td>
<td>Switch lights -1.4 (1.8)</td>
<td>-0.35 (p&lt;0.01)</td>
</tr>
<tr>
<td></td>
<td>Daylighting in CD 1.3 (1.4)</td>
<td></td>
</tr>
<tr>
<td>H2 (n = 108)</td>
<td>Switch lights -1.5 (1.8)</td>
<td>-0.41 (p&lt;0.01)</td>
</tr>
<tr>
<td></td>
<td>Daylighting in CD 1.4 (1.3)</td>
<td></td>
</tr>
<tr>
<td>H3 (n = 90)</td>
<td>Switch lights -1.2 (1.9)</td>
<td>-0.33 (p&lt;0.01)</td>
</tr>
<tr>
<td></td>
<td>Daylighting in CD 1.5 (1.3)</td>
<td></td>
</tr>
</tbody>
</table>
6.3.4 Discussions and Findings: Visual Comfort Assessments

Findings shown suggested that occupant’s curtain usage was influenced by the amount of luminance of window. Occupants in shaded room such as in H1 rarely cover their window because they perceive their interior to be dim. Meanwhile more frequent curtain usages were recorded in un-shaded room as found in H2 and H3. However, occupants in all the rooms rarely switched on the artificial lights during Clear Day even the ones staying in H1. This shows that window curtain usage was likely to be influenced by luminance of window, where it was used to offset glare and heat during clear days. Meanwhile the usage of artificial lighting was being used to equalize low external illuminance and was rarely switched on in Clear Day. These findings are in good agreements with findings from Sutter et al and Begemann et al., which stated that window curtain usage is likely to be influenced by glare and the usage of artificial lighting is rarely being used during clear day (Begemann 1997; Sutter 2006).

Findings indicate that occupants expected their naturally lit rooms to be dim (i.e.: as monitored in H1) when the daylight ratio and luminance were 0.8% and 1482 cd/m², respectively. Moreover, occupants’ perceived their naturally lit room to be bright (i.e.: as monitored in H2 and H3) when the daylight ratio and luminance reach above 2.3% and 2146 cd/m², respectively.

Findings suggested that visual comfort is more dependent on outdoor conditions, such as, weather (Table 6.10) and external illumination changes throughout the daytime (Table 6.11) than window size. This is suggested through observation in Figure 6.7, where all occupants expressed satisfactory agreement that
their window size allows adequate daylighting to occur. However, unlike H1 occupants, H2 and H3 occupants showed a higher degree of satisfaction with their window size to allow daylighting. It could be considered that the level of brightness influenced by external illumination level in a room triggers the occupants’ reaction to window size. This finding is in good agreement with findings from (Chauvel 1982; Iwata and Tokura 1998).

Summary

This chapter discussed the relationship between the objective and subjective aspects of lighting purposes in naturally lit hostel rooms in Malaysia. However, indoor environmental noise can still cause problem to the overall indoor comfort condition. In order to identify the effects of indoor environmental noise to occupants in typical multi-storey hostels in Malaysia; Chapter 7 is dedicated in assessing indoor environmental noise and acoustics comfort recorded from the selected hostels.
7.1 Introduction

Investigations on acoustics comfort in typical multi-storey hostels based on indoor environmental noise is discussed and carried out based on the following objectives:

i. To comprehensively measure the indoor environmental noise during daytime.

ii. To assess acoustics comfort experienced by occupants via questionnaire survey.

7.2 Results: Indoor environmental noise level measurement

7.2.1 Wind direction during measurement period

Table 7.1 shows the wind direction obtained from meteorological department of Malaysia for Petaling Jaya and Kuala Lumpur International Airport (KLIA) from May 12 until July 3, 2007. Because it is assumed that wind propagates noise, therefore by identifying wind direction, the relationship between the indoor environmental noises measured in hostel room can be observed against the direction of the noise source. Wind directions for H1, H2 and H3 were roughly coming from the north, south to north-west, and south, respectively.
<table>
<thead>
<tr>
<th>Date in 2007</th>
<th>Case</th>
<th>mean wind direction (°)</th>
<th>Orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td>12th May</td>
<td>H1 North</td>
<td>30</td>
<td>North</td>
</tr>
<tr>
<td>13th May</td>
<td>H1 North</td>
<td>30</td>
<td>North</td>
</tr>
<tr>
<td>14th May</td>
<td>H1 North</td>
<td>60</td>
<td>North-east</td>
</tr>
<tr>
<td>19th May</td>
<td>H1 South</td>
<td>10</td>
<td>North</td>
</tr>
<tr>
<td>20th May</td>
<td>H1 South</td>
<td>10</td>
<td>North</td>
</tr>
<tr>
<td>21st May</td>
<td>H1 South</td>
<td>350</td>
<td>North</td>
</tr>
<tr>
<td>27th May</td>
<td>H2 South-east</td>
<td>180</td>
<td>South</td>
</tr>
<tr>
<td>28th May</td>
<td>H2 South-east</td>
<td>200</td>
<td>South</td>
</tr>
<tr>
<td>29th May</td>
<td>H2 South-east</td>
<td>280</td>
<td>West</td>
</tr>
<tr>
<td>3rd June</td>
<td>H2 South-west</td>
<td>170</td>
<td>South</td>
</tr>
<tr>
<td>4th June</td>
<td>H2 South-west</td>
<td>350</td>
<td>North</td>
</tr>
<tr>
<td>5th June</td>
<td>H2 South-west</td>
<td>200</td>
<td>South</td>
</tr>
<tr>
<td>10th June</td>
<td>H2 North-east</td>
<td>190</td>
<td>South</td>
</tr>
<tr>
<td>11th June</td>
<td>H2 North-east</td>
<td>220</td>
<td>South-west</td>
</tr>
<tr>
<td>12th June</td>
<td>H2 North-east</td>
<td>140</td>
<td>South-east</td>
</tr>
<tr>
<td>17th June</td>
<td>H2 North-west</td>
<td>310</td>
<td>North-west</td>
</tr>
<tr>
<td>18th June</td>
<td>H2 North-west</td>
<td>340</td>
<td>North</td>
</tr>
<tr>
<td>19th June</td>
<td>H2 North-west</td>
<td>310</td>
<td>North-west</td>
</tr>
<tr>
<td>24th June</td>
<td>H3 West</td>
<td>160</td>
<td>South</td>
</tr>
<tr>
<td>25th June</td>
<td>H3 West</td>
<td>180</td>
<td>South</td>
</tr>
<tr>
<td>26th June</td>
<td>H3 West</td>
<td>150</td>
<td>South</td>
</tr>
<tr>
<td>1st July</td>
<td>H3 North</td>
<td>180</td>
<td>South</td>
</tr>
<tr>
<td>2nd July</td>
<td>H3 North</td>
<td>190</td>
<td>South</td>
</tr>
<tr>
<td>3rd July</td>
<td>H3 North</td>
<td>170</td>
<td>South</td>
</tr>
</tbody>
</table>

Source: Petaling Jaya and KLIA meteorological station.

### 7.2.2 Indoor environmental noise level on different vertical floor levels

Table 7.2 shows the statistical summary of noise equivalent in one hour measured in three hostels. In general, noise equivalent in one hour detected during the measurement period ranges from 43 dBA to 64 dBA. It seems that noise increases with the room floor level. Room orientation is observed to have no influence over noise occurrence indoor unless, the window is facing a noise source such as a highway.

The room with the highest noise equivalent in one hour was measured in H3 North. Findings suggest that rooms with windows facing a nearby highway without
any sound proofing mechanism received more noise from the traffic movement, such as observed in H3 North rooms regardless of their vertical room location (Figure 4.17). In H1, south facing rooms receive higher noise level because these rooms receive noise propagated from prevailing winds coming from the north, which is from the opposite direction (Table 7.1). North oriented rooms in H1, however did not receive any prevailing wind, hence lesser noise intrusion.

Meanwhile, all three rooms facing South-west in H2 have the lowest level of noise. This is because the windows for these rooms faced an open field and the rooms were located far (Figure 4.15) from the nearest highway compared to other rooms facing other orientations. Slightly higher noise level in H2 North-east rooms because these rooms are the nearest to the highway (Figure 4.15). These rooms also received prevailing wind from opposite direction, i.e. south-east to south-west, which carries noise from the highway. However, because the noise source was farther from the measured rooms’ locations compared to with other hostels, the noise level deteriorates but remains louder than measured from other rooms in H2.
Table 7.2: Indoor noise level in measured rooms on the first, fifth and top floors of H1, H2 and H3.

<table>
<thead>
<tr>
<th>Orientation</th>
<th>H1 1st flr</th>
<th>5th flr</th>
<th>9th flr</th>
<th>H2 1st flr</th>
<th>5th flr</th>
<th>7th flr</th>
<th>H3 1st flr</th>
<th>5th flr</th>
<th>10th flr</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Mean</td>
<td>47.4</td>
<td>49.2</td>
<td>49.1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>55.6</td>
<td>61.5</td>
<td>63.8</td>
</tr>
<tr>
<td>S.D</td>
<td>±9.6</td>
<td>±5.8</td>
<td>±3.3</td>
<td>±2.3</td>
<td>±1.6</td>
<td>±1.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>South Mean</td>
<td>52.6</td>
<td>54.3</td>
<td>54.8</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>S.D</td>
<td>±3.4</td>
<td>±3.2</td>
<td>±3.1</td>
<td>±2.3</td>
<td>±3.4</td>
<td>±1.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>West Mean</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>48.9</td>
<td>53.0</td>
<td>60.7</td>
</tr>
<tr>
<td>S.D</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>±2.3</td>
<td>±3.4</td>
<td>±1.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>South-East Mean</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>48.9</td>
<td>50.2</td>
<td>51.7</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>S.D</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>±5.3</td>
<td>±4.6</td>
<td>±4.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>South-West Mean</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>43.3</td>
<td>45.6</td>
<td>47.5</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>S.D</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>±4.8</td>
<td>±4.2</td>
<td>±4.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North-West Mean</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>47.1</td>
<td>49.0</td>
<td>48.6</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>S.D</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>±1.7</td>
<td>±1.7</td>
<td>±1.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North-east Mean</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>47.3</td>
<td>51.9</td>
<td>53.4</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>S.D</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>±3.5</td>
<td>±3.1</td>
<td>±3.3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: - = Not available

Noise increment relation with three different floor levels (i.e.: first, fifth and top floors) in each hostel is illustrated in Figure 7.1. Each floor has a total of 8 measured rooms. As expected, rooms in H3 by far receive the highest noise level, and then followed by rooms in H1 and finally rooms in H2. In H1, 2 dBA of noise level increment is shown as the vertical room location increases from 3m (first floor) to 15m (fifth floor). However, the noise level is constant at 52 dBA as the floor level rises from 15m to 27m (ninth or top floor). Noise from near by highway measured in top floor room could have been screened by balcony and long overhangs. Therefore it can be suggest that balcony and long overhang designs in multi-storey hostel prevent any further noise transmittance into its room.
In H2, the noise level all its measured rooms do not exceed over 50dBA. In fact, the lowest noise level recorded is found in the first floor room of this particular hostel (i.e.: 47dBA). These findings indicate that the distance of noise source is the most important factor in indoor noise occurrence prevention, even at high vertical room location of 21m above the ground.

Furthermore, because H3 is located close to a highway, the indoor noise levels shown are higher than the other two hostels. It is also observed that, indoor noise levels increases in accordance to vertical room location. This indicates that multi-storey hostel that is located near a highway and has no noise screening strategy either in its design or sound proofing mechanism between the building and the highway has high noise level that increases as the floor level increases.

Figure 7.1: Noise equivalent in one hour at different vertical room locations in H1, H2 and H3.
Figure 7.2 shows the indoor noise level collected at different room orientations in H1, H2, and H3. Each room orientation has three measured rooms. It can be suggested that the rooms that received prevailing wind from the opposite direction (Table 7.1), have higher indoor noise level. The rooms affected by this condition are H1 South, H2 North-east, and H3 North facing rooms. Meanwhile, H2 South-east facing rooms were exposed to immediate external noise level from outdoor activities that occurred during its measurement period.

Finding from Figure 7.2 also shows that indoor noise level is partially affected by balcony design. Lower noise levels are recorded in H1 North rooms (with balcony) compared to H3 North rooms (without balcony). Comparison can be made between the two hostels because, despite their same room orientation, they are also located near highways. These hostels are quite similar in height as well, that is H1 and H3 are 10 and 11 floors high, respectively.

Further analysis on relationship between noise level and weather types is summarised in Table 7.3. Noise level differed significantly between the hostels in
Rainy and Clear Days (column of Table 7.3). Noise level detected during Clear Day ($\eta_p^2 = 0.48$) varies further from each other than during Rainy Day ($\eta_p^2 = 0.33$). This is because the high noise level in H3 stands out from the rest of the hostels in both weather conditions. The noise level in H3 is higher in Clear Day than Rainy Day is partially because the warmer dry bulb temperature during the former day (Table 5.2) increases noise propagation at higher floor levels.

Moreover, in terms of noise level measured in each hostel (row of Table 7.3), only the noise level in H2 differed with a large effect size ($\eta_p^2 > 0.14$), while the noise level in H1 and H3 show less noise variations between Rainy and Clear Days. This indicates that H3 and H1 rooms are exposed to constant noise level above 55 dBA and 50 dBA, respectively, whereas H2 rooms are quieter and show slight noise intrusion in Clear Day.

Table 7.3: ANOVA repeated measures of noise equivalent in one hour, $L_{A_{eq}(t)}$ during rainy and clear day in H1, H2 and H3.

<table>
<thead>
<tr>
<th>Case</th>
<th>$L_{A_{eq}(t)}$ for different weather types</th>
<th>$\eta_p^2$ according to Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rainy day</td>
<td>Clear day</td>
</tr>
<tr>
<td>H1</td>
<td>51.5 (s.d = ±5.0)</td>
<td>50.3 (s.d = ±4.9)</td>
</tr>
<tr>
<td>H2</td>
<td>46.9 (s.d = ±5.9)</td>
<td>50.2 (s.d = ±4.7)</td>
</tr>
<tr>
<td>H3</td>
<td>55.0 (s.d = ±5.4)</td>
<td>56.6 (s.d = ±5.2)</td>
</tr>
<tr>
<td></td>
<td>$\eta_p^2$ according to Weather type</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.33 ($p&lt;0.01$)</td>
<td>0.48 ($p&lt;0.01$)</td>
</tr>
</tbody>
</table>

In terms of investigating the indoor noise level at different periods of the day, namely, morning (8:00 am to 11:59 am), afternoon (12:00 pm to 2:59 pm) and evening (3:00 pm to 5:59pm). It is assumed that the changes in traffic noise from near
by highways could have influence the indoor noise level. Results from the ANOVA repeated measures that observed mean variation between hostels and daytime periods are recorded in Table 7.4. As expected, there is indication of indoor noise level changes in relation to different times of the day (column of Table 7.4). The indoor noise level in each hostel differed significantly beyond $p<0.01$ in the morning, afternoon and evening. Results show that the noise level in the hostels ascended from H2, H1 and finally H3.

However, indoor noise level show very small indoor noise level differences throughout the day in each hostel (row of Table 7.4). This partially indicates that the farther distance from high-way, like in case of H2, predominantly controls the indoor noise level, compared to establishing noise screening strategies, such as designing rooms with balconies, like in case of H1.

Table 7.4: ANOVA repeated measures of noise equivalent in one hour, $L_{Aeq(1)}$ in the morning (8:00 am to 11:59 am), afternoon (12:00 pm to 2:59 pm) and evening (3:00 pm to 5:59 pm) in H1, H2 & H3.

<table>
<thead>
<tr>
<th>Case</th>
<th>Morning</th>
<th>Afternoon</th>
<th>Evening</th>
<th>$\eta^2$ according to Daytime period</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1</td>
<td>50.2 (s.d = ±4.9)</td>
<td>50.6 (s.d = ±4.9)</td>
<td>52.0 (s.d = ±5.9)</td>
<td>0.40 ($p&lt;0.01$)</td>
</tr>
<tr>
<td>H2</td>
<td>48.4 (s.d = ±5.6)</td>
<td>47.5 (s.d = ±5.9)</td>
<td>47.6 (s.d = ±4.8)</td>
<td>0.45 ($p&lt;0.01$)</td>
</tr>
<tr>
<td>H3</td>
<td>56.6 (s.d = ±5.8)</td>
<td>56.9 (s.d = ±5.8)</td>
<td>57.5 (s.d = ±5.4)</td>
<td>0.50 ($p&lt;0.01$)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$\eta^2$ according to Cases</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.11 ($p&lt;0.01$)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.02 ($p&lt;0.05$)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.09 ($p&lt;0.01$)</td>
</tr>
</tbody>
</table>
7.2.3 Discussions and Findings: Indoor environmental noise level

It can be suggested that indoor noise level is affected by distance from noise source. H2 rooms were observed to have the lowest indoor noise level throughout the day compared to rooms in H1 and H3 (Table 7.4).

In the case of indoor environmental noise in rooms in H3, it shows that noise source carried by the prevailing wind most likely increases the indoor noise level. In addition, due to relatively hotter dry bulb temperatures (Table 5.3), traffic noise brought in by the wind bend upwards towards cooler air, thus creating more audible noise in measured rooms on upper floor levels. The indoor noise level in H3 during hotter days rises to almost 2 dBA more than in cooler days (Table 7.3). Findings in this section are in affirmation with Meidema et al. (2005) that suggest increase in outdoor temperature produces more indoor noise level. Their investigation was conducted in the Netherlands for 7 years of seasonal monitoring.

Despite its close proximity to the high way, rooms in H1 have low indoor noise levels (i.e.: < 55 dBA), this is likely to be influenced by the fact that their windows were not facing the high-way and did not receive any prevailing wind. Furthermore, it could be suggested that balcony outside the room screens the traffic noise from entering throughout the day (Table 7.4). This particular finding is in good agreement with other works on the effects of noise level in rooms with balconies (Chand 1998; Prianto and Depecker 2002; Prianto and Depecker 2003; Tang 2005).

Findings from all three hostels show that indoor noise level increases as room altitude increases. Increased noise level on the upper rooms in H3 matches findings
from other works on indoor noise level investigation for high-rise buildings located near highways (Croome 1977; Lee 2007). It could be explained that any attenuation of sound due to ground absorption disappears as floor level gets higher, hence resulting increase in external noise level with the building height (Cowan 1994).

7.3 Results: Acoustics comfort

7.3.1 Acoustic comfort: rainy and clear days

Table 7.5 shows acoustics comfort votes during Rainy and Clear Days collected from occupants in H1, H2 and H3. Occupants participated in the subjective survey in H1, H2 and H3 were 100, 108, and 90 persons, respectively. In overall, occupants’ votes are similar regardless of different weather types and hostels. This suggests that occupants were not sensitive to the indoor noise level changes occurred in their rooms.

Table 7.5: Summary of mean estimation for occupants’ acoustics comfort during Rainy & Clear Day in H1, H2 & H3 using ANOVA repeated measures. Noisy (-3) to Quiet (3).

<table>
<thead>
<tr>
<th>Case</th>
<th>Mean acoustics comfort vote for different Weather Types</th>
<th>ηp² according to Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rainy day (RD)</td>
<td>Clear day (CD)</td>
</tr>
<tr>
<td>H1 (n = 100)</td>
<td>-0.1 (s.d = ±1.5)</td>
<td>0.2 (s.d = ±1.4)</td>
</tr>
<tr>
<td>H2 (n = 108)</td>
<td>0.0 (s.d = ±1.5)</td>
<td>0.3 (s.d = ±1.6)</td>
</tr>
<tr>
<td>H3 (n = 90)</td>
<td>-0.2 (s.d = ±1.6)</td>
<td>-0.1 (s.d = ±1.8)</td>
</tr>
<tr>
<td>ηp² according to Weather type</td>
<td>0.0 (n.s)</td>
<td>0.0 (n.s)</td>
</tr>
</tbody>
</table>

7.3.2 Acoustics comfort: daytime period

Table 7.6 shows acoustics comfort votes in the morning (8:00 – 11:59 a.m.), afternoon (12:00 – 2:59 p.m.) and evening (3:00 – 5:59 p.m.) collected from occupants in H1, H2 and H3. The medium size effect (ηp² <0.14) shown in the three
periods indicates that occupants’ acoustics comfort votes remain constant throughout the day (column and row of Table 7.6). Through this finding, it can be suggested that occupants have adapted to the level of noise available indoors and find the condition neither noisy nor quiet during the daytime despite indoor noise level changes recorded in Table 7.4.

Table 7.6: Summary of mean estimation for occupants’ acoustics comfort in the morning, afternoon and evening in H1, H2 & H3 using ANOVA repeated measures. Noisy (-3) to Quiet (3).

<table>
<thead>
<tr>
<th>Case</th>
<th>Mean acoustics comfort vote for different Daytime period</th>
<th>$\eta_p^2$ according to Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Morning</td>
<td>Afternoon</td>
</tr>
<tr>
<td>H1 (n = 100)</td>
<td>0.4 (s.d = ±1.9)</td>
<td>-0.3 (s.d = ±1.6)</td>
</tr>
<tr>
<td>H2 (n = 108)</td>
<td>0.9 (s.d = ±1.8)</td>
<td>0.4 (s.d = ±1.6)</td>
</tr>
<tr>
<td>H3 (n = 90)</td>
<td>-0.1 (s.d = ±1.9)</td>
<td>-0.1 (s.d = ±1.8)</td>
</tr>
<tr>
<td>$\eta_p^2$ according to Daytime period</td>
<td>0.05 ($p&lt;0.01$)</td>
<td>0.04 ($p&lt;0.05$)</td>
</tr>
</tbody>
</table>

7.3.3 Acoustics comfort: window function

Occupants were later asked whether they can hear the traffic noise when their windows were opened and closed. Figure 7.3 illustrates occupants in all three hostels responses toward traffic noise received in their room. In overall, the mean vote shifted slightly from ‘frequently’ when the window is opened (Figure 7.3a) to ‘neither always nor never hear the traffic noise’ (Figure 7.3b) when window is closed.
The break down of votes according to case study hostels is shown in Table 7.7. The two window functions show mean votes that differed with medium size effect ($\eta^2_p < 0.14$) from one another (column of Table 7.7). Observation revealed that occupants in H3 are the most sensitive to the indoor noise level changes, followed by occupants in H1 and finally H2 (row of Table 7.7).

Table 7.7: Summary of mean estimation for occupants’ acoustic comfort when the window is opened and closed in H1, H2 and H3 using ANOVA repeated measures. Never (-3) to Always (3).

<table>
<thead>
<tr>
<th>Case</th>
<th>Mean noise annoyance vote for different window function</th>
<th>$\eta^2_p$ according to Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Window open</td>
<td>Window close</td>
</tr>
<tr>
<td>H1 (n = 100)</td>
<td>1.2 (s.d = ±1.6)</td>
<td>0.5 (s.d = ±1.6)</td>
</tr>
<tr>
<td>H2 (n = 108)</td>
<td>0.3 (s.d = ±1.9)</td>
<td>-0.6 (s.d = ±1.8)</td>
</tr>
<tr>
<td>H3 (n = 90)</td>
<td>1.3 (s.d = ±2.0)</td>
<td>0.2 (s.d = ±1.9)</td>
</tr>
<tr>
<td>$\eta^2_p$ according to Weather type</td>
<td>0.06 ($p&lt;0.01$)</td>
<td>0.10 ($p&lt;0.01$)</td>
</tr>
</tbody>
</table>
Table 7.8 presents the mean vote of occupants’ level of annoyance toward external noise, (i.e.: traffic noise). It indicates that all occupants are ‘slightly annoyed’ (point: -1.0) with the external noise. The mean indoor noise levels for H1, H2 and H3 are 52 dBA, 48 dBA and 58 dBA, respectively (Table 7.4).

Table 7.8: Summary of vote whether external noise annoys occupants or not using ANOVA repeated measures. Annoyed (-3) to Not Annoyed (3).

<table>
<thead>
<tr>
<th>Mean Votes</th>
<th>H1</th>
<th>H2</th>
<th>H3</th>
<th>( \eta_p^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Does external noise annoy occupants?</td>
<td>-0.6 (s.d = ±1.8)</td>
<td>-0.8 (s.d = ±1.9)</td>
<td>-0.7 (s.d = ±1.8)</td>
<td>0.0 (n.s)</td>
</tr>
</tbody>
</table>

7.3.4 Discussions and Findings: Acoustic Comfort Assessments

Occupants’ votes indicated that they have adapted to the level of noise experienced indoors and found the condition neither noisy nor quiet during the daytime despite indoor noise level changes recorded. Moreover, there is no indication of variation in occupants’ annoyance towards external noise in the three hostels (i.e.: similar ‘slightly annoyed’ vote in H1, H2 and H3) even though H3 rooms showed higher level of indoor noise than the rooms in the other two hostels. This reaction was probably due to the fact that the noise level detected was still tolerable to the listeners. Student occupants in H3 could have anticipated that their room may receive the level of noise evidenced because they were located close to busy high-ways. Furthermore, findings shown are also in good agreement with (Zannin 2003; Lee 2007), which suggested that listeners can adapt to acoustic conditions that do not exceed the mean value of 62 to 65dBA.


**Summary**

Objective and subjective measurements have been used to evaluate the acoustical influences on Malaysian typical multi-storey hostels at different floor levels, room orientation, weather and daytime periods.

The following chapter discusses the potential of thermal, visual and acoustics integration in assessing the overall comfort satisfaction of occupants staying in typical multi-storey hostels in Malaysia.
CHAPTER 8

OVERALL INDOOR COMFORT SATISFACTION ASSESSMENTS

8.1 Introduction

This chapter is dedicated to provide results on occupants’ overall indoor comfort satisfaction based on the following objectives:

i. To identify the mean overall indoor comfort satisfaction in H1, H2 and H3.

ii. To assess the relationships between the overall indoor comfort satisfaction votes with sets of architectural features and individual indoor comfort perceptions through multiple linear regression.

The summary description of indoor climate conditions in all of the measured rooms is presented in the following heading.

8.2 Summary descriptions of indoor climate conditions in measured rooms

It can be summarised that in each hostel, the indoor operative temperature showed temperature difference of less than 1°C (peak temperature) for rooms at different floor levels and orientations. The subjective survey indicated that student occupants did not respond differently for different floor levels and rooms orientation. Comparison across hostels showed that rooms in un-shaded hostels were about 3°C (peak temperature) warmer than the rooms in shaded hostel. Student occupants’ responses indicated that the rooms in shaded hostel were perceived to be cooler than
the rooms in un-shaded hostels, which showed good agreement with the indoor operative temperature measurements.

Daylight ratio measurements in individual hostels showed less than 0.2 % difference at different floor levels and room orientations. Comparison across the hostels indicated that un-shaded rooms, especially rooms in H2 (i.e.: maximum daylight ratio of 5.0 %), showed a brighter daylight ratio typically greater than 4.5% than in shaded rooms in H1 (i.e.: minimum daylight ratio of 0.5%). The visual comfort votes suggested that student occupants in both shaded and un-shaded rooms did not show different reaction to their rooms’ daylighting conditions. Luminance level increases in relation to the floor level. The highest luminance level was collected from west facing room located on the top floor of H3. Subjective surveys revealed that the student occupants in un-shaded rooms showed higher annoyance level toward glare than the student occupants staying in shaded rooms.

In each of the hostel, sound pressure level increases in relation to increasing floor level. Comparison across the hostels indicated that the sound pressure level in un-shaded rooms were 12 dBA higher than the shaded rooms. Subjective surveys suggested that the student occupants showed no different response towards their indoor noise level, even though relatively high sound pressure level (i.e.: 64 dBA) was measured in H3 rooms, particularly on the top floor.
8.3 Overall indoor comfort satisfaction in typical multi-storey hostels

Table 8.1 presents the mean vote of overall indoor comfort satisfaction. H1 and H3 occupants voted that they are quite satisfied (close to point: 2). H2 occupants show lesser level of satisfaction (point: 1) then the other two hostels. Through this observation, it shows that the indoor climate in H1 and H3 provide slightly more satisfactory indoor comfort condition than in H2.

Cross-examination with findings in Table 5.16 indicates that occupants in H2 expressed that their rooms were warmer throughout the day compared to occupants in H1 and H3. Meanwhile, visual (Table 6.11) and acoustic (Table 7.6) conditions in H2 do not show extreme comfort votes (i.e.: dark or bright; and quiet or noisy). However, H2 occupants show the highest vote in curtain usage than occupants in H1 and H3. The pulling of curtain is done to reduce the effect of glare (Figure 6.8). It can be interpreted that occupants’ indoor thermal perception is partially associated with the level of glare evidence in their room. Therefore, it can be suggested that the overall indoor comfort satisfaction is most likely to be influenced by indoor thermal condition rather than through visual or acoustics conditions.

Table 8.1: Summary of vote for overall indoor comfort satisfaction using ANOVA repeated measures. Dissatisfied (-3) to Satisfied (3).

<table>
<thead>
<tr>
<th>Mean Votes</th>
<th>H1 (n = 90)</th>
<th>H2 (n = 90)</th>
<th>H3 (n = 90)</th>
<th>$\eta^2_p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall indoor comfort satisfaction</td>
<td>1.5 (s.d = ±1.1)</td>
<td>1.1 (s.d = ±1.2)</td>
<td>1.5 (s.d = ±1.2)</td>
<td>0.04 (p &lt; 0.05)</td>
</tr>
</tbody>
</table>
8.4 Relationships between the overall indoor comfort satisfaction votes with architectural features and individual indoor comfort perceptions

8.4.1 Overall indoor comfort satisfaction and architectural features

Table 8.2 shows the relationship between overall indoor satisfaction votes as dependent variable with three independent variables, namely floor level, room orientation and shading ratio in H1, H2 and H3. None of the independent variables show significant relationship with the dependent variable. This indicates that occupants in typical multi-storey hostels in Malaysia do not considered the following architectural features as important in influencing their overall indoor satisfaction.

Table 8.2: Relationship between overall indoor comfort satisfaction and architectural features using multiple linear regression.

<table>
<thead>
<tr>
<th>Dependent variable:</th>
<th>H1 (n = 90)</th>
<th>H2 (n = 90)</th>
<th>H3 (n = 90)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall indoor comfort satisfaction</td>
<td>Standardized Coefficients</td>
<td>Sig.</td>
<td>Standardized Coefficients</td>
</tr>
<tr>
<td>(Constant)</td>
<td>0.00</td>
<td></td>
<td>0.12</td>
</tr>
<tr>
<td>Floor level</td>
<td>0.10</td>
<td>0.24</td>
<td></td>
</tr>
<tr>
<td>Room orientation</td>
<td>-0.03</td>
<td>0.81</td>
<td>-0.08</td>
</tr>
<tr>
<td>Shading ratio</td>
<td>-0.21</td>
<td>0.08</td>
<td>0.06</td>
</tr>
</tbody>
</table>

\[ r = 0.18; R^2 = 0.03 \]
\[ r = 0.23; R^2 = 0.05 \]
\[ r = 0.15; R^2 = 0.02 \]

8.4.2 Overall indoor comfort satisfaction and Individual indoor comfort perceptions

Results from the relationship between overall indoor satisfaction and individual indoor comfort perceptions in H1, H2 and H3 are shown in Table 8.3. It can be observed that only very few indoor conditions that contribute to the overall indoor comfort satisfaction (i.e.: dependent variable). Independent variables that show significant relationship with the dependent variable at least beyond \( p<0.05 \) level are
written in bold and underline font style. Through the observation, it can be considered that occupants in H1 that were satisfied with their thermal comfort during Rainy Day were more likely to be satisfied with their overall indoor comfort condition. However, the overall indoor comfort perceived by occupants in H3 was more influenced by their thermal comfort during Clear Days. In H2, their occupants’ overall indoor comfort satisfaction was mainly governed by their satisfaction of thermal comfort in Clear Day, followed by thermal comfort in Rainy Day and finally the indoor noise level.

The reasons behind the strong relationship between thermal satisfactions with the dependent variable is cross-examined with the mean operative temperature and mean thermal comfort votes during both Rainy and Clear Days (Table 5.5 and Table 5.15, respectively). It can be interpreted that even though H2 received the lowest operative temperature, its thermal comfort vote indicated that occupants here expressed that their rooms were warmer than the other hostel rooms. Further observation in occupants’ reaction to glare revealed that occupants in H2 has the highest mean of curtain usage (Figure 6.7), thus partially suggesting that rooms receiving high amount of glare throughout the day (Table 6.9) are expected to be warmer by their occupants. Therefore it can be concluded that glare is most likely to be associated with thermal comfort, hence also affects the overall indoor comfort satisfaction.

In terms of indoor noise level relationship with the dependent variable, it can partially indicated that occupants in H2 were more sensitive to their indoor noise level, perhaps due to the fact that H2 received the lowest indoor noise level than the other hostels (Table 7.4).
Table 8.3: Relationship between overall indoor comfort satisfaction (DV) and Individual indoor comfort perceptions (IV) using multiple linear regression.

<table>
<thead>
<tr>
<th>Dependent variable:</th>
<th>H1 (n = 90)</th>
<th>H2 (n = 90)</th>
<th>H3 (n = 90)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall indoor comfort satisfaction</td>
<td>S. C Sig.</td>
<td>S. C Sig.</td>
<td>S. C Sig.</td>
</tr>
<tr>
<td>(Constant)</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Satisfied with thermal comfort (RD)</td>
<td>0.27</td>
<td>0.01</td>
<td>0.22</td>
</tr>
<tr>
<td>Satisfied with thermal comfort (CD)</td>
<td>0.09</td>
<td>0.35</td>
<td>0.38</td>
</tr>
<tr>
<td>Satisfied with visual comfort</td>
<td>0.21</td>
<td>0.06</td>
<td>0.03</td>
</tr>
<tr>
<td>Satisfied with glare</td>
<td>0.08</td>
<td>0.48</td>
<td>0.07</td>
</tr>
<tr>
<td>Satisfied with indoor noise level</td>
<td>0.17</td>
<td>0.06</td>
<td>0.21</td>
</tr>
</tbody>
</table>

\[ r = 0.54; R^2 = 0.29 \quad r = 0.59; R^2 = 0.35 \quad r = 0.51; R^2 = 0.26 \]

Note: S.C = standardized coefficient

8.5 Prioritisation of indoor conditions based on the student occupants’ indoor comfort perception

287 college-aged female students in three different hostels in Klang Valley, Malaysia were collected. The mean ranks are shown in Table 8.4 for H1, H2 and H3 occupants, respectively. Descending sequential order of the indoor conditions as ranked by occupants is shown in parenthesis next to each mean rank. ‘7’ is considered the most influential indoor condition, while ‘1’ is the weakest. The mean ranks in each hostel show significant mean difference beyond \( p < 0.01 \) between the indoor conditions. Low ranking difference level in H1 (i.e.: \( \chi^2 = 20.0 \)) indicates that ranks between the indoor conditions show closer degree of difference than ranks in H2 (i.e.: \( \chi^2 = 26.2 \)) and H3 (i.e.: \( \chi^2 = 60.5 \)).

In H1, occupants’ indoor comfort is strongly affected by external noise, indoor air temperature, room airiness, sunlight heat, glare, room humidity and finally
adequate daylighting. It can be assumed that, because H1 rooms were perceived to be slightly cooler than the two other hostels (Table 5.16), occupants here could be in accord with their indoor thermal conditions, but show slightly higher annoyance to external noise. Observation from Table 8.4 also confirms that occupants in H1 were less worried about their daylighting condition, even though the rooms were dimmer than the other hostel rooms (Table 6.6).

There is a close resemblance of indoor comfort ranks from occupants in H2 and H3. In H2, occupants’ indoor comfort was strongly affected by indoor air temperature, sunlight heat, external noise, glare, room airiness, adequate daylighting and room humidity. Occupants in H3 also ranked the air temperature to be the most important indoor condition, followed by sunlight heat, external noise, room airiness, adequate daylighting, room humidity and finally glare. H2 and H3 occupants’ ranks clearly show that they were strongly affected by their rooms’ indoor thermal condition, namely, through air temperature and sunlight heat from the window. Occupants in both hostels also showed less interest in daylighting, room humidity and glare.

Table 8.4: Friedman Test means ranks from H1, H2 and H3 occupants

<table>
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<tr>
<th>Indoor Conditions</th>
<th>Mean Rank H1 (n = 92)</th>
<th>Mean Rank H2 (n = 107)</th>
<th>Mean Rank H3 (n = 88)</th>
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<td>Indoor air temperature</td>
<td>4.45 (6)</td>
<td>4.97 (7)</td>
<td>4.80 (7)</td>
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<tr>
<td>Airy indoor condition</td>
<td>4.14 (5)</td>
<td>3.98 (3)</td>
<td>4.10 (4)</td>
</tr>
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<td>Humid indoor condition</td>
<td>3.62 (2)</td>
<td>2.88 (1)</td>
<td>3.57 (2)</td>
</tr>
<tr>
<td>Sunlight heat from window</td>
<td>3.99 (4)</td>
<td>4.26 (6)</td>
<td>4.28 (6)</td>
</tr>
<tr>
<td>Adequate daylighting</td>
<td>3.58 (1)</td>
<td>3.48 (2)</td>
<td>3.72 (3)</td>
</tr>
<tr>
<td>Glare from window</td>
<td>3.64 (3)</td>
<td>4.18 (4)</td>
<td>3.39 (1)</td>
</tr>
<tr>
<td>External noise annoyance</td>
<td>4.59 (7)</td>
<td>4.25 (5)</td>
<td>4.15 (5)</td>
</tr>
</tbody>
</table>

$\chi^2 (6) = 20.0; p<0.01$  $\chi^2 (6) = 60.5; p<0.01$  $\chi^2 (6) = 26.2; p<0.01$
8.6 Discussions and Findings

Findings showed that occupants in H1 rooms, which are shaded and larger in volume, are more satisfied with their overall room condition. However, warmer and glareier indoor conditions reduced the level of overall indoor comfort satisfaction as seen in H2. Studies have shown that occupants’ indoor thermal perception can be partially associated with glare (Boubekri 1991; Foster and Oreszczyn 2001; Nicol 2006). The rooms that received large patch of glare were usually perceived to be warmer, thus making occupants thermally uncomfortable. On the other hand, shaded rooms were usually perceived to be cooler by local Malaysians (Lim. 1987; Hanafi 1994). Based on this suggestion, it could be the reason why student occupants in shaded rooms showed higher the level of overall indoor comfort satisfaction than the ones staying in un-shaded rooms.

Occupant behaviour in non-air conditioned rooms with one ceiling fan were observed. Through their overall indoor comfort satisfaction votes, it is suggested that occupants were tolerant with the indoor climate of their rooms (Table 8.1), thus indicating that it is not necessary to employ climate-controlled strategies for typical hostels in Malaysia. One ceiling fan per-room (for room volume less than 50m$^3$) is sufficient. The findings are in good agreement with Nicol (2005).

Based on the findings from the previous Chapters 5, 6 and 7 as well as the current chapter, it can be suggested that students in hostels have innate expectations of their thermal, visual and acoustic indoor conditions. Therefore, most of them have adapted to the particular conditions. Changes in their subjective votes were detected whenever the weather condition and daytime periods changed, thus indicating that the

Chapter 8, page 8
prevailing outdoor conditions could influence occupants’ indoor comfort perceptions. The indoor condition in the morning and Rainy Days were perceived to be cooler than those expressed during the afternoon, evening and Clear Days. This notion is also in agreement with findings from De Dear and co-workers (De Dear 1994; De Dear and Brager 2002).

From the observations made, warmer indoor condition can result in auditory discomfort. Occupants that perceived their room to be warm, such in the case of occupants in H2, also showed higher level of noise annoyance even though the noise level measured in H2 measured rooms were the lowest among the hostels. This finding is in good agreement with findings from previous investigations in this particular field (Miedema 2005; Nagano and Horikoshi 2005; Kruger and Trombetta Zannin 2007).

Moreover, it can be suggested that the air temperature influence on thermal condition is the most important factor that contributes to occupants’ overall indoor climate satisfaction. The occupants consider lighting and humidity levels of lesser influence. This is similar to finding from Humphreys (Humphreys 2005). The observations shown indicated that occupants have no problems with their daylighting and humidity conditions but felt that the air temperature could be slightly cooler in order to improve their overall indoor climate satisfaction.
Summary

The overall indoor comfort satisfaction as perceived by occupants of typical multi-storey hostels in Malaysia have been presented and discussed in this chapter. Prior to the assessment, summaries of the indoor climate conditions in the measured hostels are also included. This chapter exhibits the final group of findings for this thesis. Subsequently, the conclusion for the entire thesis is discussed in the following chapter.
CONCLUSIONS AND RECOMMENDATIONS

9.1 Introduction

This chapter concludes the overall discussions and findings of the thesis. The chapter includes the following sections: summary of the thesis problems; conclusions based on thesis aim and objectives: guidelines from improving indoor comfort in typical multi-storey hostels in Malaysia and suggestions for future investigations.

9.2 Summary of the thesis problem

Occupants’ indoor comfort in dwelling has rarely been considered by architects and decision makers in Malaysia. Dwellings here are built without much regards to their local environmental conditions but rather only to fit the demands of mass-production. Low-cost multi-storey dwelling is the one with the least consideration in catering for indoor comfort. This particular building type is built with cheap insulation; no shading device; and relatively small windows. Not much consideration has been put into improving the function of balcony design in multi-storey dwelling. Moreover, because more and more multi-storey dwellings are been built close to mains road, traffic noise disturbance could increase occupants’ level of annoyance while indoors. The problems mentioned have not only caused poor indoor comfort condition in the dwellings but have also increased energy consumption due to the usage of air-conditioning systems.
9.3 Conclusions based on thesis aim and objectives

The thesis aim is to identify the comfort perception of students living in typical multi-storey hostels in Malaysia. The characteristic of a typical multi-storey hostel is defined as having only one ceiling fan, non-air-conditioned, more than 5 storey high and installed with side-window in each of its room. Focus is given on how student has perceived their indoor thermal, visual and acoustics conditions.

9.3.1 Review of indoor climate assessments related to occupant’s indoor comfort in multi-storey buildings

Not many works have been undertaken to assess occupant’s indoor comfort perceptions in Malaysian dwellings, especially in the thermal and acoustics fields. This urges the author to gather literatures on thermal comfort investigations during the summer season and from countries that have similar climate with Malaysia. Meanwhile, just a handful of investigations were available that emphasized on the effects of occupant’s acoustics comfort caused by traffic noise. On the other hand, studies on daylighting and visual comfort were more popular among Malaysian researchers.

Studies on thermal investigations have shown that darker skin people are more tolerant to warmer surroundings. Acclimatization actions, such as drinking cool water, wearing light clothing and switching on fans increase thermal comfort level of occupants in hot countries. Daylighting investigations show that hot climate countries, like Malaysia, have the potential to apply daylighting into its buildings, however, thermal discomfort complaints increases as a reaction to glare that is evidenced indoor. In terms of acoustic investigations, the review of sound propagation shows
that noise is more audible at the higher floor levels of a building, especially in hot countries. In the end of the literature review, the author found that investigations in indoor comfort should be done collectively in order to obtain a more realistic result that resembles occupants’ actual indoor comfort perception.

Furthermore, the parameters to be investigated for Malaysian application have also been identified, which are been described in detail in Chapters 2 and 3. Studies on non-air-conditioned buildings show that thermal comfort investigations looks into the relationship of outdoor temperature (i.e.: dry bulb temperature) and indoor temperature (i.e.: operative temperature) and then cross-examining them with occupant’s thermal comfort votes. Daylighting investigation typically in Malaysia is done through daylight ratio. Meanwhile in acoustics investigation, readings are measured in terms of A-weighted sound levels, as in many references.

9.3.2 Illustration of integrated indoor comfort factors in typical multi-storey hostels in Malaysia using Architectural Systems

The importance of understanding the relationship of three main components namely, the building; its immediate outdoor-indoor environment; and occupants’ indoor comfort encouraged the author to explore the concept of Architectural Systems. In this thesis, Architectural Systems represents the total pattern of phenomenon that creates an environment surrounding the occupants of typical multi-storey hostels in Malaysia. The three main components of the systems are illustrated within this research’s boundary. Weaknesses and strengths of a particular building envelope design are highlighted. The degree of interaction between the components
illustrated is designed to be easily comprehended by an architect that is not trained in the field of Architectural Systems (Figure 4.2).

Each main component consists of several sub components, thus making the system more robust in order to represent the actual condition analysed (Figure 4.5). The detail explanation on the conceptual development of the illustrated system is included in Chapter 4.

9.3.3 Indoor thermal, visual and noise levels in typical multi-storey hostels in Malaysia through objective measurements

Objective measurements consisted of operative temperature; illumination and sound pressure level were conducted to examine the indoor condition in three existing typical multi-storey university hostels in Klang Valley, Malaysia namely, Twelfth Residential College, Universiti Malaya (H1); Eleventh Residential College, Universiti Putra Malaysia (H2); and Murni Student Apartment, Universiti Tenaga Nasional (H3). Twenty four rooms were measured. The entire objective measurement period was successfully conducted within a 56 days period. Measurement period started on 12 May and ended on 19 July 2007. The measurement was successfully conducted within the time, manpower and instruments limitations proposed by the author. The details of the objective measurements procedures and descriptions of the selected buildings are described in Chapter 4.

Findings from the objective measurements showed that the outdoor condition directly influence the visual and acoustics conditions recorded in un-shaded rooms (i.e.: H2 and H3). Rooms that were shaded (i.e.: H1) via projected balcony giving a
shading ratio of 0.9 and long roof overhang with shading ratio of 1.6 were dimmer yet provide sufficient daylighting (i.e.: >0.5% of daylight ratio) and screen traffic noise (i.e.: the noise level were < 55dBA). The high operative temperatures (i.e.: from 29°C to 30°C) recorded among the three hostels could not be avoided in Malaysia due to high mean outdoor temperature and mean relative humidity of 28°C and 80%, respectively. However, findings showed that there was no significant indoor operative temperature relationship with either floor level or room orientation.

In sum, findings from the objective measurement show that rooms that were shaded via balcony and / or long roof overhang, such as found in H1 are considered more successful in controlling the level of daylighting and external noise level. However, shaded indoor conditions could not reduce the indoor operative temperature.

9.3.4 Occupants’ indoor thermal, visual and noise level perceptions in typical multi-storey hostels in Malaysia through questionnaire survey

309 female college-aged occupants responded to the questionnaire survey that was conducted in three typical multi-storey university hostels in the Klang Valley. The method of investigation is described in detail in Chapter 4, while the sample distribution is included in Chapter 5. The survey has obtained the occupant’s assessments regarding the following indoor comfort conditions: thermal comfort; visual comfort; and acoustic comfort.

The approach used in this study has made it possible to understand the contradiction between strictly objective findings, which regarded the indoor operative
Conclusions and Recommendations

temperature, daylight ratio and noise level, and the subjective findings through the questionnaire about student occupants’ indoor perceptions. As a result, it was possible to identify that despite the temperature, daylight ratio and sound pressure level differences recorded in the objective measurement, the subjective analyses have showed almost identical thermal, visual and noise annoyance level perceptions regardless of the room location (i.e.: floor level and orientations) in each hostel. However, comparison between thermal comfort response from student occupants in shaded (via projected balconies) and un-shaded rooms showed that occupants staying in shaded rooms (in H1) were slightly cooler than the ones staying in un-shaded rooms (in H2 and H3). The fact that findings from subjective surveys sometimes are not in agreement with the objective measurements showed that both means of investigations should be used in conjunction when evaluating indoor comfort.

9.3.5 Overall indoor comfort satisfaction (combination of thermal, visual and acoustics comfort perceptions)

Occupants in H1 and H3 expressed that they were quite satisfied with their overall indoor comfort condition. Occupants in H2 however were slightly less satisfied in this matter. Cross-examinations with their individual thermal, visual and acoustic comfort votes found that occupants in H2 perceived their room to be warmer and glarier. Their thermal discomfort response was due to occupants’ indoor thermal perception that is partially associated with the level of glare available in their room. Therefore, it can be concluded that rooms with large patches of glare on the floor are perceived to be warm by occupants in Malaysia.
Further indoor condition ranking showed that indoor thermal condition was the most important factor that contributes to the occupant’s overall indoor comfort satisfaction. Observations on occupants’ showed that the ceiling fan is sufficient in maintaining their thermal comfort and installing air-conditioning system would be inappropriate. On the other hand, daylighting and humidity levels were considered of lesser influence. A detailed explanation regarding this discussion is included in Chapter 8.

9.4 Guidelines for improving occupant’s indoor comfort conditions in typical multi-storey hostels in Malaysia

Based on the research findings the guidelines for improving occupants’ indoor comfort condition in typical multi-storey hostels in Malaysia are recommended as follows:

- Overall indoor comfort survey shows that occupant are strongly influenced by their indoor thermal condition. Therefore, it is suggested that future dwelling is designed to provide with cooler indoor thermal comfort, such as building multi-storey dwellings with projected balconies, and install more operable side windows.

- Based on the noise level measurement, measured rooms that were closer to traffic noise source received higher noise disturbance. Even though, occupants show neutral response towards this acoustics condition, dwellings should be located about 100m from main road and screened by noise buffer walls or trees in order to reduce the effects of traffic noise.
Conclusions and Recommendations

- An indoor comfort expectation survey should be administered to potential occupants in order to understand their level of thermal, visual and acoustic expectations. When those expectations are met, it is believed that energy consumption could also be minimized.

- Dimmer rooms as a result from shaded room condition, should have task lights installed.

9.5 Suggestions for future investigations

The findings and recommendations stated are limited to the scope of this study. Many related issues and detail findings need further investigations in order to achieve satisfactory indoor climate performance in typical multi-storey hostels in hot humid climate country. Several suggestions for future research are recommended to refine the detail procedures carried out in this thesis.

- The author hopes that the architectural system illustrated can be developed into a decision making tool that complements virtual architectural environment programs in the future.

- It is recommended that future research focus on the advantages of cross-ventilation in multi-storey dwellings. Emphasis could be given on how much the air temperature is reduced and does the airflow improve.

- Further investigation on the indoor noise level generated from adjacent rooms is required, especially in typical multi-storey dwellings in hot humid countries.
The materials used in the construction of this type of building is usually of poor quality, thus more noise screening strategies could be implemented.

The works carried out in this thesis have suggested foundations for research on the indoor climate and comfort perceptions in typical multi-storey hostels of a hot-humid climate condition. These contributions are hoped to broaden the scope of researches in similar fields.
References
References


References


References


References


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analysis in conjunction with an objective analysis." Environmental Impact Assessment Review 23(2): 245-255.


Appendices
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|                   | ![Image](image13) | ![Image](image14) | ![Image](image15) | ![Image](image16) |

Cloud cover images, 10
<table>
<thead>
<tr>
<th>Time</th>
<th>8:00 a.m.</th>
<th>12:00 p.m.</th>
<th>3:00 p.m.</th>
<th>5:00 p.m.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hostel &amp; Date</td>
<td>H3W 26/6/07</td>
<td>H3W 26/6/07</td>
<td>H3W 26/6/07</td>
<td>H3W 26/6/07</td>
</tr>
<tr>
<td>Hostel &amp; Date</td>
<td>H3N 1/7/07</td>
<td>H3N 1/7/07</td>
<td>H3N 1/7/07</td>
<td>H3N 1/7/07</td>
</tr>
</tbody>
</table>

Cloud cover images, 11
<table>
<thead>
<tr>
<th>Time/Hostel &amp; Date</th>
<th>8:00 a.m.</th>
<th>12:00 p.m.</th>
<th>3:00 p.m.</th>
<th>5:00 p.m.</th>
</tr>
</thead>
<tbody>
<tr>
<td>H3N 2/7/07</td>
<td><img src="image1" alt="Image" /></td>
<td><img src="image2" alt="Image" /></td>
<td><img src="image3" alt="Image" /></td>
<td><img src="image4" alt="Image" /></td>
</tr>
<tr>
<td>H3N 3/7/07</td>
<td><img src="image5" alt="Image" /></td>
<td><img src="image6" alt="Image" /></td>
<td><img src="image7" alt="Image" /></td>
<td><img src="image8" alt="Image" /></td>
</tr>
</tbody>
</table>

Cloud cover images, 12
Dear participant, thank you for participating. The objective of this survey is to identify the indoor environment comfort condition in university halls of residences in Klang Valley. You would have to rate the thermal, visual & acoustic comfort of your current room. Please take about 10 minutes of your time to fill up this questionnaire. Your co-operation is highly appreciated.


Yours truly,

Nur Dailiah Dahlia | PhD Student | Welsh School of Architecture | Cardiff University | Bute Building | King Edward VII Avenue | Cardiff, CF10 3NB | email add.: dahiannd@cardiff.ac.uk

Glossary/Glosari:

**Thermal comfort** — comfort state that is influenced by air movement, air temperature, radiant temperature & humidity. It is usually measured indoors.

**Keselesaan terma** — keadaan selesa yang dipengaruhi oleh pergerakan udara, suhu udara, suhu sinaran dan kelembapan. Ia selalunnya diukur di dalam bangunan.

**Visual comfort** — comfort state that is influenced by adequate amount of illumination in order to perform a task and without any discomfort glare intrusions. In this questionnaire form, this comfort type is divided into two separate sections.

**Keselesaan visual** — keadaan selesa yang dipengaruhi oleh jumlah pencahayaan yang cukup bagi melaksanakan tugas dan tanpa gangguan dari silau yang kurang menyelesaikan. Dalam borang kaji ini, keselesaan ini dibahagikan kepada dua seksyen yang berbeza.

**Acoustic comfort** — comfort state that has sufficient ‘quiet’ environment to enable the task to be carried out comfortably and without unwanted sounds (noise) distraction.

**Keselesaan akustik** — keadaan selesa yang mempunyai keadaan ‘tenang’ yang cukup untuk membolehkan tugas dijalankan secara selesa dan tanpa ganggu dari bunyi bising.

**Cloudy/Rainy days** — days that are overcast and wet most of the time.

**Hari-hari mendung/hujan** — hari-hari yang mendung dan sangat lembap hampir sepanjang masa.

**Clear days** — days that are dry, hot and have slightly clouded sky most of the time.

**Hari-hari cerah** — hari-hari yang kering, panas dan menpunyai langit yang sedikit berawan hampir sepanjang masa.

To be filled by survey participant:

<table>
<thead>
<tr>
<th>Date of Survey: ______/2007</th>
<th>Room No. / Floor: <strong><strong><strong>/</strong></strong></strong></th>
<th>Time: ______</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tariikh kaji selidik</td>
<td>No. Bilik/Tingkat:</td>
<td>Masa</td>
</tr>
</tbody>
</table>

| Name of your hall of residence & university: ____________________________ |
| Nama kolej kediaman dan universiti anda _______________________________|
SECTION A: PERSONAL DETAILS. Question A.1 to A.7. Tick (✓) one answer only.


A.1. Gender
Jantina

- Male/ Lelaki
- Female/ Perempuan

A.5. How long do you usually stay in your room if there isn't any class in a day?
Berapa lama selalunya anda berada di bilik jika seharian tiada kelas?

- All day
- Only during the night, to sleep

A.2. Age Group
Kelompok Usia

- 41 & above
- 36 - 40
- 31 - 35
- 26 - 30
- 21 - 25
- 20 & below

A.6. What do you usually do in your room?
Apa yang anda selalunya lakukan di bilik anda?

- Studying
- Socialising with mates
- Relaxing in between classes
- Just for sleeping
- All the above

A.3. Type of degree studying:
Jenis ijazah yang sedang diambil:

- Bachelor Degree/ Diploma
- Master/ PhD

A.7. Usually I wear ... on days that are mostly:
Saya selalunya memakai ... pada hari yang kerap:

- Rainy
- Hot

- Short sleeves t-shirt – track suit/ jeans
- Long sleeves t-shirt – track suit/ jeans
- Sleeveless t-shirt – sarong*/ shorts
- Short sleeves t-shirt – sarong*/ shorts
- Just sarong*/ shorts
- Sweater - t-shirt – track suit/ jeans

* Sarong: kain batik/ pelekat

A.4. How long have you been staying in this hostel?
Berapa lama anda tinggal di asrama ini?

- 3 years and over
- 2 years
- 1 year
- Less than a year

For office use. Do not write in this box (Untuk kegunaan pejabat. Jangan menulis di dalam kotak ini):

- Location of room: floor
- Window orientation:
- Floor reflectance factor/ colour:
- Wall reflectance factor/ colour:
- Ceiling reflectance factor/ colour:
- Do the window have curtain? (Yes / No)
- Is the window open or close? (open / close)

End of Section A
**SECTION B: THERMAL COMFORT RATING**

*Seksyen B: Penilaian Keselasaan Tema*

Instruction for questions B.1- B.11: Tick (✓) in the appropriate box.

*Arahan untuk soalan B.1-B.11: Tandakan (✓) pada kotak yang sesuai.*

<table>
<thead>
<tr>
<th>Scale values:</th>
<th>Example of answer: What do you feel now? <em>Apakah yang anda sedang rasai?</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - Cold/ Sejuk</td>
<td>Cold 1 - 2 - 3 - 4 - 5 - 6 - 7 Hot</td>
</tr>
<tr>
<td>2 - Cool/ Dingin</td>
<td></td>
</tr>
<tr>
<td>3 - Slightly cool/ sedikit dingin</td>
<td></td>
</tr>
<tr>
<td>4 - Neutral/ Neutral</td>
<td></td>
</tr>
<tr>
<td>5 - Slightly warm/ sedikit hangat</td>
<td></td>
</tr>
<tr>
<td>6 - Warm/ hangat</td>
<td></td>
</tr>
<tr>
<td>7 - Hot/ panas</td>
<td></td>
</tr>
</tbody>
</table>

**Over the last 6 months/ Sepanjang 6 bulan yang lalu:**

**B.1** What do you usually felt when you were in your room during CLOUDY/ RAINY DAYS?

*Apa yang anda selalu rasa apabila anda berada dalam bilik anda pada hari-hari MENDUNG/ HUJAN?*

**B.2** What do you usually felt when you were in your room during CLEAR DAYS?

*Apa yang anda selalu rasa apabila anda berada dalam bilik anda pada hari-hari CERAH?*

**B.3** You feel that this room is ... during CLOUDY/ RAINY DAYS.

*Anda rasa bagai bilik ini ... pada hari-hari MENDUNG/ HUJAN.*

**B.4** You feel that this room is ... during CLEAR DAYS.

*Anda rasa bagai bilik ini ... pada hari-hari CERAH.*

**B.5** When the window is opened, you feel... during CLOUDY/ RAINY DAYS.

*Apabila tingkap dibuka, anda rasa ... pada hari-hari MENDUNG/ HUJAN.*

**B.6** When the window is opened, you feel... during CLEAR DAYS.

*Apabila tingkap dibuka, anda rasa ... pada hari-hari CERAH.*

**B.7** You feel that this room is... during CLOUDY/ RAINY DAYS.

*Anda rasa bagai bilik ini ... pada hari-hari MENDUNG/ HUJAN.*

**B.8** You feel that this room is ... during CLEAR DAYS.

*Anda rasa bagai bilik ini ... pada hari-hari CERAH.*

**B.9** Are you satisfied with the thermal condition of this room during CLOUDY/ RAINY DAYS?

*Adakah anda berpuas hati dengan keadaan terma bilik anda semasa hari-hari MENDUNG/ HUJAN?*

Continue to next page *Bersambung di muka surat seterusnya.*
B.10 Are you satisfied with the thermal condition of this room during CLEAR DAYS?
Adakah anda berpuas hati dengan keadaan terma bilik anda semasa hari-hari CERAH?

B.11 Through your experience in the room during the day time, how do you classify your thermal comfort during these hours (regardless of any weather condition):
Sepanjang pengalaman anda dalam bilik ini sewaktu siang, bagaimana anda mengklasifikasikan keselesaan terma anda di waktu-waktu berikut (tanpa berdasarkan kepada mana-mana keadaan cuaca):

i) Morning/ Pagi (8.00am - 11.59am)

ii) Afternoon/ Tengah hari (12.00pm - 4.29pm)

iii) Evening/ Petang (4.30pm - 6.30pm)

Instruction for questions B.12- B.17: Tick (V) in the appropriate box.
Arahan untuk soalan B.12-B.17: Tandakan (√) pada kotak yang sesuai.

Scale values:
1 - Disagree/ tidak setuju
2 - Quite disagree/ agak tidak setuju
3 - Slightly disagree/ sedikit tidak setuju
4 - Neither disagree or agree/ tidak kedua-duanya
5 - Slightly agree/ agak setuju
6 - Neither agree or disagree/ tidak kedua-duanya
7 - Agree/ setuju

B.12 Do you agree that the window size is alright for you?
Adakah saiz tingkap anda sesuai bagi anda?

B.13 When the window is opened, is your room draughty?
Apabila tingkap dibuka, adakah bilik anda berangin?

B.14 Do you like the room to be airy?
Adakah anda ingin bilik ini menjadi berangin?

B.15 When the window is opened, is your room humid?
Apabila tingkap dibuka, adakah bilik anda lembap sepanjang masa?

B.16 Do you like the room to be humid?
Adakah anda ingin bilik ini menjadi lembap?

B.17 Do you close the window on CLEAR days?
Adakah anda menutup tingkap di bilik anda pada hari-hari CERAH?
SECTION C: ILLUMINATION RATING

Seksyen C: Penilaian Pencahayaan

Instruction for questions C.1- C.7: Tick (✓) in the appropriate box.

Arahan untuk soalan C.1-C.7: Tandakan (✓) pada kotak yang sesuai.

Over the last 6 months/ Sepanjang 6 bulan yang lalu:

C.1 Describe your visual comfort in this room when only depending on natural lighting during CLOUDY/RAINY DAYS?

Nyatakan keselesaan visual anda ketika di bilik ini apabila ia hanya bergantung pada cahaya suria semasa hari-hari MENDING/HUJAN?

C.2 Describe your visual comfort in this room when only depending on natural lighting during CLEAR DAYS?

Nyatakan keselesaan visual anda ketika di bilik ini apabila ia hanya bergantung pada cahaya suria semasa hari-hari CERAH?

C.3 Is natural lighting alone enough to light this room during CLOUDY/RAINY DAYS?

Adakah bilik ini dapat diterangi dengan cahaya suria sahaja semasa hari-hari MENDING/HUJAN?

C.4 Is natural lighting alone enough to light this room during CLEAR DAYS?

Adakah bilik ini dapat diterangi dengan cahaya suria sahaja semasa hari-hari CERAH?

C.5 Are you satisfied with the natural lighting condition of this room?

Adakah anda berpuas hati dengan keadaan cahaya suria bilik anda?

C.6 On a CLEAR day, do you switch on the artificial lights during the daytime?

Pada hari yang CERAH, adakah anda memasang lampu pada waktu siang?

C.7 Through your experience in the room during the daytime, how do you classify the room’s brightness during these hours (regardless of any weather condition):

Sepanjang pengalaman anda dalam bilik ini sewaktu siang, bagaimana anda mengklasifikasikan tahap keterangan bilik ini di waktu-waktu berikut (tanpa berdasarkan kepada mana-mana keadaan cuaca):

i) Morning/ Pagi (8.00am-11.59am)

ii) Afternoon/ Tengah hari (12.00pm—4.29pm)

iii) Evening/ Petang (4.30pm- 6.30pm)
SECTION D: GLARE SENSATION RATING
Seksyen D: Penilaian Rasa Silau

Instruction for questions D.1- D.6: Tick (✓) in the appropriate box.
Arahan untuk soalan D.1-D.6: Tandakan (✓) pada kotak yang sesuai.

<table>
<thead>
<tr>
<th>Scale values:</th>
<th>1 - Not noticeable/ tidak dirasai</th>
<th>2 - Slightly not noticeable/ sedikit tidak dirasai</th>
<th>3 - Quite not noticeable/ agak tidak dirasai</th>
<th>4 - Acceptable/ boleh diterima</th>
<th>5 - Slightly irritating/ sedikit tidak menyenangkan</th>
<th>6 - Quite irritating/ agak tidak menyenangkan</th>
<th>7 - Irritating/ tidak menyenangkan</th>
</tr>
</thead>
</table>

Over the last 6 months/ Sepanjang 6 bulan yang lalu:

D.1 Do you agree that the window serves its purpose in allowing natural light into the room?
Adakah anda bersetuju bahawa tingkap ini membenarkan kemasukan cahaya surai ke dalam bilik ini?

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agree setuju</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disagree tidak setuju</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

D.2 Do you experience glare* sensation during CLOUDY/ RAINY DAYS when you’re in the room?
Adakah anda merasa silau* apabila berada dalam bilik ini pada hari-hari MENDUNG/ HUJAN?

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Never</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Always selalu</td>
<td></td>
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</tr>
</tbody>
</table>

D.3 On a CLEAR day, do you pull on the window curtains during the daytime?
Pada hari yang CERAH, adakah anda menggunakan langsir tingkap pada waktu siang?

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Never</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Always selalu</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

D.4 Do you experience glare* sensation during CLEAR DAYS when you’re in the room?
Adakah anda merasa silau* apabila berada dalam bilik ini pada hari-hari CERAH?

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Never</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Always selalu</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

(*glare - caused by striking light from the outside window but the indoor is dark)
*silau - disebabkan oleh cahaya yang terlalu terang dari luar tingkap tetapi bilik berada dalam keadaan gelap)

D.5 Are you satisfied with the overall glare condition of this room?
Adakah anda berpuas hati dengan keadaan silau dalam bilik anda secara menyeluruh?

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dissatisfied tidak puas hati</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Satisfied berpuas hati</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

D.6 Through your experience in the room during the daytime, how do you classify your glare sensation during these hours (regardless of any weather condition): Sepanjang pengalaman anda dalam bilik ini sewaktu siang, bagaimana anda mengklasifikasikan rasa silau anda di waktu-waktu berikut (tanpa berdasarkan kepada mana-mana keadaan cuaca):

i) Morning/ Pagi (8.00am-11.59am)
Not noticeable Tidak dirasai

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not noticeable Tidak dirasai</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irritating tidak menyenangkan</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

ii) Afternoon/ Tengah hari (12.00pm- 4.29pm)
Not noticeable Tidak dirasai

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not noticeable Tidak dirasai</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irritating tidak menyenangkan</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

iii) Evening/ Petang (4.30pm- 6.30pm)
Not noticeable Tidak dirasai

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not noticeable Tidak dirasai</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irritating tidak menyenangkan</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

End of Section D
**SECTION E: NOISE RATING**

*Seksyen E: Penilaian Tahap Kebisingan*

**Instruction for questions E.1- E.7:** Tick (✓) in the appropriate box.

*Arahan untuk soalan E. 1-7: Tandakan ✓ pada kotak yang sesuai.*

**Example of scale values:**

1 - Annoyed/ terganggu
2 - Quite annoyed/ agak terganggu
3 - Slightly annoyed/ sedikit terganggu
4 - Neither / tidak kedua-duanya
5 - Slightly not annoyed/ sedikit tidak terganggu
6 - Quite not annoyed/ agak tidak terganggu
7 - Not annoyed / tidak terganggu

---

### Over the last 6 months/ Sepanjang 6 bulan yang lalu:

<table>
<thead>
<tr>
<th>Question</th>
<th>Rating Values</th>
<th>Scale Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>E.1</td>
<td>Do you find this room to be... during CLOUDY/RAINY DAYS, if the window is opened?</td>
<td>Noisy</td>
</tr>
<tr>
<td>E.2</td>
<td>Do you find this room to be... during CLEAR DAYS, if the window is opened?</td>
<td>Noisy</td>
</tr>
<tr>
<td>E.3</td>
<td>Can you hear road traffic noise when the window in your room is opened?</td>
<td>Never</td>
</tr>
<tr>
<td>E.4</td>
<td>Can you hear road traffic noise when the window in your room is closed?</td>
<td>Never</td>
</tr>
<tr>
<td>E.5</td>
<td>If you can hear the road traffic noise, will it be annoying to you?</td>
<td>Annoyed</td>
</tr>
<tr>
<td>E.6</td>
<td>Are you annoyed with the external noise condition heard when you are in this room?</td>
<td>Annoyed</td>
</tr>
<tr>
<td>E.7</td>
<td>Through your experience in the room during the day time, how do you classify the exterior noise level heard from your room during these hours: Sepanjang pengalaman anda dalam bilik ini sewaktu siang, bagaimanakah anda mengklasifikasikan bunyi bising dari luar yang kedengaran dari bilik anda di waktu-waktu berikut:</td>
<td></td>
</tr>
</tbody>
</table>

#### i) Morning/ Pagi (8.00am-11.59am)

#### ii) Afternoon/ Tengah hari (12.00pm- 4.29pm)

#### iii) Evening/ Petang (4.30pm- 6.30pm)

---

*End of Section E*
SECTION F: PARTICIPANT'S OPINION
Seksi F: Pendapat peserta

Instruction for question F.1: Fill in the boxes below with vote from 1 (not influenced) to 7 (influenced).

Arahan untuk soalan F.1: Isikan kotak-kotak di bawah dengan undian dari 1 (tidak mempengaruhi) hingga 7 (mempengaruhi).

Example:
Which of these films influenced you the most?
Filem manakah paling meninggalkan kesan pada anda?

**Answer sample/ contoh jawapan:**

<table>
<thead>
<tr>
<th>Film/ Filem</th>
<th>Answer</th>
<th>Not Influenced / tidak mempengaruhi</th>
<th>Influenced / mempengaruhi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brave heart</td>
<td>7</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>300</td>
<td>5</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Lord of the Ring</td>
<td>6</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Saving Private Ryan</td>
<td>2</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Black Hawk Down</td>
<td>1</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Starwars</td>
<td>4</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>The Patriot</td>
<td>3</td>
<td>7</td>
<td></td>
</tr>
</tbody>
</table>

F.1 Which of these conditions most influenced your comfort sensation when you are in your room?

Keadaan yang manakah yang paling mempengaruhi rasa selesa anda semasa anda berada di bilik anda?

**Comfort types**

<table>
<thead>
<tr>
<th>Jenis-jenis keselesaan</th>
<th>Answer</th>
<th>Not Influenced / tidak mempengaruhi</th>
<th>Influenced / mempengaruhi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indoor Temperature</td>
<td></td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>Airy indoor condition</td>
<td></td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Humid indoor condition</td>
<td></td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Sunlight heat from window</td>
<td></td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Adequate natural lighting</td>
<td></td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>Glare sensation from window</td>
<td></td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>External noise annoyance</td>
<td></td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

Continue to next page/ Bersambung di muka surat seterusnya.
F.2. What is your overall satisfaction rate for your room's indoor comfort condition?
Apakah nilai keseluruhan kepuasan anda untuk keadaan keselesaan bagi dalaman bilik anda?

Instruction for question F.3: Write your opinion in the space provided.
Arahan untuk soalan F.3: Isikan pendapat anda di ruang yang disediakan.

F.3. Do you have any recommendations to improve your room's comfort condition?
Adakah anda mempunyai cadangan untuk membaiki tahap keselesaan bilik anda?

End of Section F

THANK YOU
A.1 Descriptions of indoor climate conditions in measured rooms

Description of indoor climate conditions in all of the measured rooms are summarised in Figure A.1. Student occupants’ subjective responses toward their thermal comfort, visual comfort and noise annoyance are presented in Table A.1. Moreover, Table A.2 shows the student occupants’ subjective responses in shaded and un-shaded rooms.

Table A.1: Relationship between student occupants’ subjective responses (thermal comfort; visual comfort; and noise annoyance level) and architecture features (floor level and room orientation) within each hostel.

<table>
<thead>
<tr>
<th>Hostels</th>
<th>Thermal Comfort</th>
<th>Visual Comfort (daylight)</th>
<th>Visual Comfort (glare)</th>
<th>Noise annoyance level</th>
</tr>
</thead>
<tbody>
<tr>
<td>HI</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Floor level</td>
<td>$r = 0.38^*$</td>
<td>$r = 0.13^*$</td>
<td>$r = 0.17^*$</td>
<td>$r = 0.05^*$</td>
</tr>
<tr>
<td>n = 100</td>
<td>Room Orientation</td>
<td>$r = 0.07^*$</td>
<td>$r = -0.14^*$</td>
<td>$r = 0.12^*$</td>
</tr>
<tr>
<td>HI</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Floor level</td>
<td>$r = 0.06^*$</td>
<td>$r = 0.08^*$</td>
<td>$r = 0.01^*$</td>
<td>$r = 0.42$</td>
</tr>
<tr>
<td>n = 108</td>
<td>Room Orientation</td>
<td>$r = 0.05^*$</td>
<td>$r = 0.06^*$</td>
<td>$r = 0.11^*$</td>
</tr>
<tr>
<td>HI</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Floor level</td>
<td>$r = 0.01^*$</td>
<td>$r = -0.12^*$</td>
<td>$r = 0.13^*$</td>
<td>$r = -0.05^*$</td>
</tr>
<tr>
<td>n = 90</td>
<td>Room Orientation</td>
<td>$r = 0.04^*$</td>
<td>$r = 0.24$</td>
<td>$r = -0.11^*$</td>
</tr>
</tbody>
</table>

*Note: (*) Pearson correlations show no significant values

Table A.2: Thermal comfort, visual comfort and noise annoyance level votes by student occupants living in shaded and un-shaded rooms.

<table>
<thead>
<tr>
<th>Hostels</th>
<th>Thermal Comfort</th>
<th>Visual Comfort (daylight)</th>
<th>Visual Comfort (glare)</th>
<th>Noise annoyance level</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shaded rooms</td>
<td>-1.4 (s.d = ±1.0)</td>
<td>0.5 (s.d = ±1.6)</td>
<td>-1.0 (s.d = ±1.8)</td>
<td>0.0 (s.d = ±1.5)</td>
</tr>
<tr>
<td>H2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Un-shaded rooms</td>
<td>-0.1 (s.d = ±1.4)</td>
<td>0.6 (s.d = ±1.5)</td>
<td>-0.4 (s.d = ±2.0)</td>
<td>0.1 (s.d = ±1.5)</td>
</tr>
<tr>
<td>H3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Un-shaded rooms</td>
<td>0.6 (s.d = ±0.9)</td>
<td>0.5 (s.d = ±1.6)</td>
<td>-0.7 (s.d = ±1.9)</td>
<td>-0.1 (s.d = ±1.7)</td>
</tr>
</tbody>
</table>
Figure A.1: Maximum value of operative temperature, daylight ratio and indoor noise level at different floor levels and room orientations in: a) H1; b) H2 and c) H3.
A.1.1 Relationship between thermal objective measurements and subjective surveys

Observation in each hostel suggests that indoor operative temperature showed little variation (i.e.: <1°C) between rooms located on the lower floors and the ones located on the top floor. There were also very little temperature difference detected (i.e.: < 1°C) among different measure room orientations (Figure A.1). In Table A.1, the student occupants’ responses indicate that student occupants living in each of the hostel were not sensitive to the changes in their indoor thermal regardless to their room’s floor level and orientation. It could be concluded that, student occupants’ lack of sensitivity towards their thermal condition was due to not much temperature difference occurred at different floor levels and room orientations.

However, the maximum indoor operative temperature measured in un-shaded rooms (collected from H3 and H2 rooms) showed up to 3°C warmer than shaded rooms (collected from H1). Cross examination with Table A.2 suggested that student occupants in shaded rooms (in H1) expressed that their rooms were somewhat cool (i.e.: point = -1.4 or in between slightly cool and cool). Meanwhile, student occupants in un-shaded rooms (in H2 and H3) gave higher thermal comfort votes (i.e.: mean votes that vary from neutral to slightly warm) from indicating that their rooms were slightly warmer. Therefore, it can be suggested that findings from the student occupants’ thermal comfort surveys are in agreement with the indoor operative temperature measurements collected from typical multi-storey hostels in Malaysia when asked to identify their thermal comfort responses between shaded and un-shaded rooms.
A.1.2 Relationship between visual objective measurements and subjective surveys

Findings from each hostel's visual condition through daylight ratio measurement as presented in Figure A.1 showed that rooms in top floor H1 were about 0.5% and 1.0% lower than the rooms in first floor and fifth floors, respectively. Moreover, daylight ratio results in different measured room orientations showed very slight variation (i.e.: about 0.1 to 0.2%). Therefore, it could be suggested that rooms that were shaded by projected balcony provide a more uniform daylight ratio despite their different floor level and orientations.

On the other hand, rooms in H2 (un-shaded rooms) showed higher variation in daylight ratio measured in different room orientations. Rooms facing the north-west and north-east received higher daylight ratio than rooms facing the south-east and south-west. In H3, there is not much daylight ratio difference occurred between rooms facing north and west. Furthermore, daylight ratio measurements do not show much variation in relation to floor level in H2 and H3 rooms.

In terms of visual comfort findings in Table A.1, there is a weak correlation ($r = 0.24; p<0.05$) between student occupants' response to their daylighting condition in regards to different room orientations in H3. The rest of the responses suggested that student occupants had accepted their daylighting and glare conditions by providing visual comfort votes that are almost identical regardless of the rooms' different floor levels and orientations. The student occupants' visual comfort votes are shown in Table A.2 where point 0.5 to 0.6 for visual comfort through daylighting perception represents neutral (i.e.: neither dark nor bright) vote category. Meanwhile, point -1.0
until -0.4 for visual comfort through glare sensation indicates quite not noticeable until slightly not noticeable vote category. Therefore it can be suggested that student occupants in both shaded and un-shaded rooms did not show different reaction to their rooms’ daylighting condition. However, student occupants in un-shaded rooms especially in H2 show slightly higher awareness towards glare than the student occupants in H3 and followed by H1.

A.1.3 Relationship between noise level objective measurements and subjective surveys

Figure A.1 shows an increase in noise level measured as the floor level increases in all of the hostels. Comparison among different hostels suggested that rooms that were not screened by projected balconies can receive up to 12 dBA higher than the rooms that were screened.

In terms of occupants’ noise level annoyance, there is only one weak correlation significance between occupants’ votes (in H2) in regards to different floor levels. The rest of the responses suggested that student occupants showed almost identical votes in their indoor noise level regardless of the rooms’ different floor levels and orientations. The student occupants’ noise annoyance level votes are shown in Table A.2 where point 0.1 to -0.1 represents neutral (i.e.: neither annoyed nor not annoyed) vote category. From this finding, it can be suggested that student occupants had adapted to their indoor noise level, even though relatively high sound pressure level was measured in H3 rooms, particularly on the top floor.
Field Measurement and Subjects' Votes Assessment on Thermal Comfort in High-rise Hostels in Malaysia

N.D. Dahlan, P.J. Jones, D.K. Alexander, E. Salleh and D. Dixon

Abstract

The need to design for low energy consumption dwellings has induced Malaysian architects to design naturally ventilated high-rise hostels (HH), near the capital, Kuala Lumpur. Objective and subjective measurements for thermal comfort investigations were conducted in two high-rise university hostels located in Universiti Malaya, Petaling Jaya (HH1) and Universiti Putra Malaysia, Serdang (HH2) from May 12 to June 19 in 2007. Eighteen rooms located at first, fifth, and top floor of each HH were measured for different orientations. The measured rooms were naturally ventilated with ceiling fans. Thermal comfort variables were measured prior to the subjective measurement. A total of 208 student occupants responded to the questionnaire. Subjects with 6 months and over living experience in those HH were selected randomly. This study was aimed: (1) to assess the indoor microclimate of each naturally ventilated HH, (2) to identify student occupants' thermal sensation during rainy and clear day, and (3) to simulate the neutral operating temperature for rooms in naturally ventilated high-rise hostels. Findings revealed that room in HH1 which is located on high land and shaded has a more constant operating temperature distribution than rooms in HH2 that is located on lower land and un-shaded. Operating temperature ranges for HH1 and HH2 were 27–31°C and 26–41°C, respectively. Results suggested that there is also a possibility that thermal comfort is achievable in shaded naturally ventilated hostels with a window-to-wall ratio of 0.35 where the internal-external relative humidity is above 70% RH, especially in south-facing rooms..

Introduction

Thermal comfort surveys in tropical countries near to the equator have been actively assessed by researchers since 1949 [1–3]. The importance of comfort generally in a...
Building design has been widely translated into several cost-housing designs, traditional Malay houses, terraced houses, walk-up flats, and class-rooms but none have been conducted in high-rise domestic buildings. Malaysia is a maritime country close to the equator. It has abundant sunshine but it is rare to have a full day with a completely clear sky. The average sunshine is around 6 h. The daily range of temperature in Malaysia is from a low of 24°C up to 38°C with the lowest temperature usually recorded during the night. Relative humidity can be as low as 42% to as high as 94%. Malaysia’s annual evaporation rate is about 4-5 mm per day depending on the cloud cover and air temperature (Malaysian Meteorological Department, 2007, unpublished data). Because of its hot and humid climate, cooler days are often recorded with low evaporation rate, high relative humidity value, cloudier sky (7 oktas), and wet while warmer days are usually the opposite.

As a country that is progressing towards an energy consumption conscious target, buildings are designed to enable natural ventilation. However, a naturally ventilated building cannot give a thermally comfortable environment in Malaysia. At the very least a ceiling fan needs to be installed to lessen the heat gain indoors. With the aim of achieving low energy consumption, several high-rise university hostels near Kuala Lumpur are built without air-conditioners installed. Instead passive strategies like long overhangs and balconies are included in some of these buildings. Two high-rise hostels (HH) were selected for this study. They were the 12th Residential College, Universiti Malaysia (HH1) and the 11th Residential College, Universiti Putra Malaysia (HH2). HH1 is located in the Petaling Jaya area at a latitude of 3° 6’ N, longitude of 101° 39’ east of Greenwich and 60.8 m above sea-level. HH2 is located in the Sepang with latitude of 2° 44’ N, longitude of 101° 42’ E and is 16.3 m above sea-level.

Malaysia’s equatorial climate and the need to use less energy in high-rise dwellings would be expected to militate against thermal comfort. The first objective of this study was to comprehensively measure the indoor microclimate conditions of selected HH samples and their relationship to the external air temperature. The second objective was to assess subjective thermal sensation experienced by HH occupants on both rainy and clear days. The final objective was to compare the neutral operating temperatures obtained from three models, namely, optimum thermal comfort model, linear regression between subjects’ thermal sensation votes (TSV) with the operative temperature model and linear regression between predicted mean votes (PMV) against the operative temperature model.

Methodology

Case Study Buildings – Room Description

The dimensions and window-to-wall ratio (WWR) for typical rooms in HH1 and HH2 are as follows:

(a) HH1: 4.90 x 3.30 x 3.00 m³ (lwh) (not including balconies); WWR = 0.35
(b) HH2: 4.30 x 3.60 x 2.90 m³ (lwh); WWR = 0.26

Three rooms vertically located with the same orientation were chosen to be monitored simultaneously, namely, on the first, fifth, and top floors for each HH. These different room locations were chosen to measure the indoor air temperature differences slightly above ground, middle and top level of a high-rise dwelling building. For HH1, north and south orientations were taken into account. For HH2, rooms were monitored at north, south, east, and west orientations. The occupancy number for HH1 and HH2 rooms was two and three persons, respectively. HH1 is the only hall of residence that has balconies (2.0 m projection). Each HH has different window designs, namely, adjustable louver windows with transparent polymer finish in HH1; and set of six top hung windows (single glazing) in HH2 (Figure 1). These high-rise hostels are naturally ventilated. A ceiling fan is the only mechanical ventilation unit used in those buildings.

Field Measurement

Three rooms at different locations, namely, at the lowest, middle, and top floor for each available room orientation were simultaneously used for measurement for 3 days. At the end of 3 days, another set of rooms were measured with a different room orientation. The room’s dimension, WWR and shading strategies were identified before starting the measurements. Shading strategy was identified based on whether the room was designed with a balcony or had long overhangs or not. Windows were left open during the measurement period.

A 1000 Series Squirrel data logger (Eltek Ltd, Cambridge, UK) together with Durac Windows software was used throughout the field measurements. Sensors connected to the logger were temperature and relative humidity probes, a globe temperature probe, and two bead temperature sensors. The temperature and relative humidity probe is 260 mm in length and 25 mm in diameter with solid-state temperature and humidity sensor devices which change its electrical characteristics in response to extremely small changes in indoor temperature and humidity. Operating temperature is measured as the internal temperature of a hollow sphere (painted in black) that is exposed to the environment. The internal temperature of the sphere indicates the balance between heat lost and gained from radiation and convection. It has an operating range from -40°C to +60°C. The 38 mm 'ping pong ball' was used as the sphere for the sensor because of its fast response and heat exchange properties, which are similar to a human body at typical indoor air speeds [12,13]. Therefore, in order to understand occupants’ indoor thermal response, their thermal sensation votes were regressed against the operating temperature. Climatology data used for HH1 and HH2 were collected from Petaling Jaya and Kuala Lumpur International Airport (KLIA) near Sepang weather stations.

Subjective Survey

Occupants who had experience of living 6 months and over in these hostels were selected at random. Occupants were all female because the selected hostels accommodated female students only. The measurement period was also limited. Occupants were approached individually in their rooms and were asked if they want to participate in the questionnaire survey. Occupants who participated were not given any monetary reward but agreed to fill in the questionnaire forms voluntarily.
In the questionnaire surveys, occupants were asked to vote on their thermal comfort during rainy days and clear days over the last 6 months. The questions used for this investigation were as follows:

(1) What do you usually feel when you are in your room during rainy days?
(2) What do you usually feel when you are in your room during clear days?

Clear and rainy day conditions were chosen so that it would be easier for subjects to relate their thermal comfort with the warmest and coolest conditions throughout the year. A 7-point thermal sensation scale was provided in the questionnaire form, which consisted of: cold (-3); cool (-2); slightly cool (-1); neutral (0); slightly warm (+1); warm (+2) and hot (+3). A glossary of the terms used in the questionnaire was provided on the first page of the form.

Predicting Subjects' Thermal Neutrality

Subjects' thermal neutrality was predicted using three types of calculations. The first calculation adopts the optimum thermal comfort, $T_{opt}$, model for naturally ventilated buildings [14]. This model is estimated using the following equation:

$$T_{opt} = 17.6 + 0.31 T_{indoor}$$  \(1\)

where, $T_{indoor}$ is the mean outdoor dry bulb temperature. Then, the range of temperature around $T_{opt}$ corresponding to 90% thermal acceptability is defined. This percentage of acceptability is applied as a function of operative temperature in order to produce a 90% acceptable comfort zone.

The second calculation was done by constructing a linear regression model relating STSV to $T_{indoor}$ and the mean relative humidity measured. Meanwhile, the third calculation was done through linear regression models relating PMV with similar operating temperatures mentioned earlier. The PMV model was constructed according to ISO7730 standard and run using C++ Program version 6.0. Meanwhile the statistical analyses were done using SPSS Program version 12.

Results and Discussions

Indoor Temperature Measurement

Twenty-four hour measurements over 3-day periods for six different orientations from both HH1 (i.e., orientations north and south) and HH2 (i.e., orientations: north, south, east, and west) were recorded. Weather data during the measurement periods were obtained and correlated against the indoor microclimate conditions measured, namely, air temperature, operating temperature, relative humidity, and indoor air temperature, operating temperature, and relative humidity. Statistical summary of the dry bulb temperature during the measurement period is shown in Table 1. The first indoor operating temperature measurement was done in HH1 (north-oriented rooms) on May 12 while the final measurement was conducted in HH2 (west-oriented rooms) on June 19. External air temperature sensors recorded ranges from 24°C to 34°C. The most constant temperature was from May 27 to 29 and the least constant temperature was from May 12 to 15.

Table 2 shows the summary of operating temperatures for HH1 and HH2. Overall the operating temperature ranged from 26°C to 41°C. The mean operating temperature for HH1 and HH2 for the 18 room/days ranged from 28°C to 30°C. Table 3 shows the summary of indoor relative humidity for HH1 and HH2. Overall measured relative humidity ranged from 35% to 81%.

The mean relative humidity for HH1 and HH2 over 18 room/ days ranged from 64% to 74%. All of the rooms measured showed temperatures above 26°C. Most rooms had relative humidity around 70% except for HH1 north-oriented room on June 19. External air temperature sensors recorded ranges from 24°C to 34°C. The most constant temperature was from May 27 to 29 and the least constant temperature was from May 12 to 15.

Table 3 shows the relationship between mean internal operating temperature, relative humidity for each HH and their external counterparts. Indoor microclimate conditions are derived as dependent variables (DV) whereas external microclimate conditions are derived as independent variables (IV). Indoor air temperature for rooms in HH1 and HH2 show moderate significant influence with their dry bulb temperature showing slope gradient ($r^2$) and Pearson linear correlation ($r$) of 0.633, 0.769 for HH1 and 0.560, 0.769 for HH2.
Table 4. Pearson linear correlation between indoor air temperature, operating temperature and relative humidity against dry bulb temperature and relative humidity in HH1 and HH2

<table>
<thead>
<tr>
<th></th>
<th>HH1 (WWR = 0.35)</th>
<th>HH2 (WWR = 0.26)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DV: Indoor air temperature</td>
<td>( R = 0.746, p &lt; 0.001 )</td>
<td>( R = 0.746, p &lt; 0.001 )</td>
</tr>
<tr>
<td>DV: Dry bulb temperature</td>
<td>( R = 0.741, p &lt; 0.001 )</td>
<td>( R = 0.747, p &lt; 0.001 )</td>
</tr>
<tr>
<td>DV: Operating temperature</td>
<td>( R = 0.741, p &lt; 0.001 )</td>
<td>( R = 0.747, p &lt; 0.001 )</td>
</tr>
<tr>
<td>DV: Dry relative humidity</td>
<td>( R = 0.600, p &lt; 0.001 )</td>
<td>( R = 0.684, p &lt; 0.001 )</td>
</tr>
</tbody>
</table>

0.748 for HH2. A similar relationship is also shown between operating temperature and dry bulb temperature, i.e., \( R^2 = 0.548 \), \( r = 0.741 \) and \( R^2 = 0.558 \), \( r = 0.747 \) for HH1 and HH2, respectively. However, internal and external relative humidity relationships in HH1 show higher slope gradient and Pearson linear correlation values than HH2, i.e., \( R^2 = 0.640 \), \( r = 0.800 \) and \( R^2 = 0.468 \), \( r = 0.684 \) for HH1 and HH2, respectively. These correlations indicate that relative humidity in HH1 rooms closely resemble the external relative humidity compared to rooms in HH2. The closer the internal-external relative humidity difference but not above 70% RH increases the chances of achieving thermal comfort in a country with a hot and humid climate [17].

Furthermore, HH2 rooms have the least constant operating temperature in comparison with HH1 rooms. The widest HH2 temperature deviation was found in west-oriented rooms (Table 2) even though the external air temperature was not the least constant throughout the survey period (Table 1). This indicates that west-oriented rooms without shading and WWR of 0.26 causes greater distribution of operative temperature that here ranged from 26°C to 41°C. Meanwhile the temperatures measured from HH1 were the most constant compared to the other two HHs. South-oriented rooms in HH1 had the most constant range at all three floors (Table 2), despite the less than constant external air temperature of ±5°C standard deviation (Table 1). This shows that south-oriented rooms with shading and WWR of 0.35 causes a more constant operating temperature distribution that ranges from 27°C to 31°C. The results also show that temperatures in all HH1 rooms, the hostel located in a hilly area, were more constant than in all the HH2 rooms which are located at lower elevation.

To identify the temperature response at different room locations, the maximum operating temperature measured was plotted against rooms at first, fifth, and top floor of each HH (Figure 2). In HH1, similar peak operating temperatures (32°C) were recorded at all three-room locations. In HH2, the warmest rooms were located at the seventh (top) floor where a maximum temperature of 41°C was measured while the fifth and first floor rooms remained at 34 and 33°C, respectively. Figure 3(a) shows maximum temperature for each HH against room orientations while Figure 3(b) shows maximum temperature for rooms with shading (HH1) and without shading (HH2). The highest temperatures recorded were in west-oriented rooms in HH2. The other three orientations all had temperatures below 35°C.

**Subjective Surveys**

Subjects were 18-26-year-old undergraduate students doing sedentary type activities. Subjects were asked to tick the types of clothing they wore during RD and CD. Six clothing types estimated in accordance with ISO 7730 are shown in Table 3.

The summary of subjects’ daily clothing type for the HHs is shown in Table 5. Type 2 clothing wear was the most frequently worn clothing type during both day conditions for the two HH. During CD, large majority of subjects wore type 4 clothing while during rainy days, most of them were comfortable wearing type 1 and others type 6 clothing.

To analyze the vote distribution, clo values for RD and CD were combined and plotted against temperature (Figure 4). Combined votes also gave a more linear relationship when correlated against temperatures in HH1 and HH2. The 208 subjects response to peak temperatures and the wider operating temperature distribution found in HH2 rooms lead to a more significant relationship with the subjects’ clo value compared to HH1. Results for subjects’ clo value during RD and CD regressed with operating temperature in HH1 and HH2 showing low significant regression analysis of 0.419 and 0.483, respectively. Mean clo value recorded for subjects in HH1 and HH2 was 0.5, indicating that subjects preferred to wear underwear, short sleeves t-shirt with track suit or jeans on both rainy and clear days (Table 5).

Significant mean differences beyond \( p < 0.001 \) were detected when ANOVA repeated measures were used between STVS votes for RD and CD. Large size effects (\( n = 0.78 \)) were also detected for both RD and CD in: HH1, \( F(1, 96) = 33.7 \) (RD: m = 1.61; s.d = 0.84, CD: m = 0.51; s.d = 0.86) and HH2, \( F(1, 102) = 35.4 \) (RD: m = 1.36; s.d = 0.82, CD: m = 0.83; s.d = 1.00). Figure 5 shows the STVS for RD and CD in HH1 and HH2 at different floor levels. RD votes in HH1 and HH2 are between the slightly cool and cool comfort points, while CD votes in HH1 and HH2 are between neutral and the slightly warm comfort point. Even though the mean difference between RD and CD votes in each HH show significant differences, both RD and CD votes at different floor levels show no significant differences. This indicates that subjects were not sensitive to temperature variation across different floor levels.

**Table 5. Daily wear clothing**

<table>
<thead>
<tr>
<th>Daily wear clothing</th>
<th>Clo value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1: Short sleeves t-shirt, track suit/jeans; underwear</td>
<td>0.5</td>
</tr>
<tr>
<td>Type 2: Long sleeves t-shirt, track suit/jeans; underwear</td>
<td>0.6</td>
</tr>
<tr>
<td>Type 3: Sleeveless t-shirt, sarong/shorts; underwear</td>
<td>0.7</td>
</tr>
<tr>
<td>Type 4: Short sleeves t-shirt, sarong/shorts; underwear</td>
<td>0.8</td>
</tr>
<tr>
<td>Type 5: Just sarong; underwear</td>
<td>1.0</td>
</tr>
<tr>
<td>Type 6: Sweater, cotton long sleeves; short, track suit/jeans; underwear</td>
<td>1.0</td>
</tr>
</tbody>
</table>

The summary of subjects’ daily clothing type for the HHs is shown in Table 5. Type 2 clothing wear was the most frequently worn clothing type during both day conditions for the two HH. During CD, large majority of subjects wore type 4 clothing while during rainy days, most of them were comfortable wearing type 1 and others type 6 clothing.

To analyze the vote distribution, clo values for RD and CD were combined and plotted against temperature (Figure 4). Combined votes also gave a more linear relationship when correlated against temperatures in HH1 and HH2. The 208 subjects response to peak temperatures and the wider operating temperature distribution found in HH2 rooms lead to a more significant relationship with the subjects’ clo value compared to HH1. Results for subjects’ clo value during RD and CD regressed with operating temperature in HH1 and HH2 showing low significant regression analysis of 0.419 and 0.483, respectively. Mean clo value recorded for subjects in HH1 and HH2 was 0.5, indicating that subjects preferred to wear underwear, short sleeves t-shirt with track suit or jeans on both rainy and clear days (Table 5).

Significant mean differences beyond \( p < 0.001 \) were detected when ANOVA repeated measures were used between STVS votes for RD and CD. Large size effects (\( n = 0.78 \)) were also detected for both RD and CD in: HH1, \( F(1, 96) = 33.7 \) (RD: m = 1.61; s.d = 0.84, CD: m = 0.51; s.d = 0.86) and HH2, \( F(1, 102) = 35.4 \) (RD: m = 1.36; s.d = 0.82, CD: m = 0.83; s.d = 1.00). Figure 5 shows the STVS for RD and CD in HH1 and HH2 at different floor levels. RD votes in HH1 and HH2 are between the slightly cool and cool comfort points, while CD votes in HH1 and HH2 are between neutral and the slightly warm comfort point. Even though the mean difference between RD and CD votes in each HH show significant differences, both RD and CD votes at different floor levels show no significant differences. This indicates that subjects were not sensitive to temperature variation across different floor levels.

**Table 5. Daily wear clothing**

<table>
<thead>
<tr>
<th>Daily wear clothing</th>
<th>Clo value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1: Short sleeves t-shirt, track suit/jeans; underwear</td>
<td>0.5</td>
</tr>
<tr>
<td>Type 2: Long sleeves t-shirt, track suit/jeans; underwear</td>
<td>0.6</td>
</tr>
<tr>
<td>Type 3: Sleeveless t-shirt, sarong/shorts; underwear</td>
<td>0.7</td>
</tr>
<tr>
<td>Type 4: Short sleeves t-shirt, sarong/shorts; underwear</td>
<td>0.8</td>
</tr>
<tr>
<td>Type 5: Just sarong; underwear</td>
<td>1.0</td>
</tr>
<tr>
<td>Type 6: Sweater, cotton long sleeves; short, track suit/jeans; underwear</td>
<td>1.0</td>
</tr>
</tbody>
</table>
Predicting Subjects’ Thermal Neutrality

The optimum thermal comfort, $T_{\text{com}}$, of occupants in naturally ventilated buildings in South East Asia is estimated using Equation (1). The average dry bulb temperatures, $T_{\text{avg}}$, for the month of May until July since 2002-2007 were 28.3°C in Petaling Jaya (HHI) and 28.1°C in KLIA (HH2). These months are selected to represent average dry bulb temperatures during measurement periods. Occupants’ optimum thermal comfort is thus estimated as follows:

$$T_{\text{com}}(\text{HH1}) = 17.6 + 0.31(28.3)$$
$$= 26.37°C$$

$$T_{\text{com}}(\text{HH2}) = 17.6 + 0.31(28.17)$$
$$= 26.33°C$$

The 90% acceptability for thermal comfort suggested is $T_{\text{com}} \pm 3.5°C$ [8], then temperature must not exceed:

$$= 26.37°C + 3.5°C$$
$$= 29.87°C$$

$$= 26.33°C + 3.5°C$$
$$= 29.83°C$$

Figure 6 shows the regression of subjects’ thermal sensation vote (STSV) for both RD and CD on the operating temperature in HH1 [Figure 6(a)] and HH2 [Figure 6(b)]. RD and CD regressed onto the operating temperature in HH1 and HH2 show significant Pearson linear correlation beyond $p<0.001$: $r = 0.369$ and $r = 0.325$, respectively. The relationships indicated in Figure 6 are not strong in HH1, $R^2 = 0.136$ and HH2, $R^2 = 0.106$. In HH1, the slope of the regression line is 0.421/°C, which means up to 33.3°C variation of operating temperature can cause the STSV to vary by 1. In HH2, the slope of regression line is 0.668/°C, where up to 30.1°C variation of operating temperature causes the STSV to vary by 1. The regression analysis of mean STSV during RD and CD in HH1 and HH2 gives thermally neutral temperatures of 30.9°C and 28.6°C, respectively.

The linear regression model relating PMV for HH1 and HH2 with the operating temperature are shown in Figure 7. PMV regressed on operating temperature in HH1 and HH2 shows significant Pearson linear correlation beyond $p<0.001$: $r = 0.907$ and $r = 0.922$, respectively. The relationships indicated in Figure 7 are significantly strong in HH1, $R^2 = 0.822$ and HH2, $R^2 = 0.849$. The slope for the PMV gradient in HH1 is 0.412/°C, which means up to 28.9°C variation of operating temperature can cause the PMV to vary by 1. Meanwhile, the PMV gradient in HH2 is 0.314/°C with 28.6°C variation of operating temperature causes the PMV to vary by 1. The regression analysis of mean PMV gives a thermal neutral temperature of 26.5°C in HH1 and 25.4°C in HH2. Regression results in HH1 and HH2 of
mean STSV are around 4°C higher than regression results of mean PMV.

The operating temperatures from these three calculations differed from each other. However, the optimum thermal comfort model with 90% acceptability provided closer mean neutral temperatures (29.8°C in HH1 and 28.8°C in HH2) with the mean neutral temperature calculated from a linear regression model relating STVS with the operating temperature (30.9°C in HH1 and 28.6°C in HH2) compared to a linear regression model relating PMV with operating temperature (26.5°C in HH1 and 25.4°C in HH2).

Table 6 shows the summary of PMV and STSV during both RD and CD in HH1 and HH2. A total of 208 subjects in HH1 and HH2 answered two sets of questionnaire surveys that gave a total of 416 votes. Table 7 shows the summary of PMV and STSV during both RD and CD in HH1 and HH2. The average STSV of subjects in HH1 and HH2 are −0.57 and -0.19, respectively, on the 7-point scale. These results are close to the neutral comfort point, while average PMV in HH1 and HH2 are slightly higher, namely 1.42 and 1.36, respectively, or in between the slightly warm and warm comfort points. The above findings may be explained in two ways. The first explanation is through the ‘Adaptive Theory’ which suggests that people are not passively receptive of their thermal environment [14, 18]. They adapt to their environment but may feel discomfort when change occurs. That is why most of subjects are neutrally comfortable in the current operating temperature and are more sensitive to peak temperature changes. The higher STSV acceptable parameter into the PMV model. The availability of short wave can influence the quantity of water evaporated from a surface. A low evaporation level leads to low indoor relative humidity and hence decreases occupants’ thermal comfort especially in a hot and humid climate country, where humidity is reported to have an adverse effect on comfort [17]. Through observation, measurements in rooms that were shaded, north and south-oriented received less short-wave radiation and sometimes none. But in some unavoidable cases where rooms were facing either east or west, a large patch of sunlight was usually available and increased the indoor temperature. Therefore, it would be appropriate to suggest that the PMV model should include an indoor short-wave radiation parameter in order produce results that more closely resemble occupants’ thermal comfort sensation in countries with a hot and humid climate.

**Conclusions**

Indoor microclimate measurements were made over a 3-day period in 18 different room locations in naturally ventilated high-rise hostels where the mean operating temperature ranged from 28°C to 30°C. The operating temperature in HH1 rooms, located at a higher elevation were more constant than in HH2 rooms which were located lower down. West-oriented rooms without shading and a WWR of 0.26 caused a wide distribution of operating temperature that ranged from 26°C to 41°C. South-oriented rooms with shading and WWR of 0.35 provided a more constant operating temperature distribution that ranges from 27°C to 31°C.

Some 208 college-aged female occupants of HH1 and HH2 had a mean clo value of 0.5 indicating that they preferred to wear underwear, short sleeves t-shirt with track suit or jeans during both RD and CD. The decision to combine RD and CD votes were made because operating temperatures measured were under both of those day time conditions. Subjects’ STSV in RD and CD was significant beyond p<0.001 with the operating temperature as a variable. ANOVA analyses revealed that in both HHs, STSVs during RD indicated that subjects felt between slightly cool and cool while STSVs during CD showed thermal sensation increase indicating that subjects felt between neutral and slightly warm. However, STSV during both RD and CD votes at different floor levels showed no significant differences in both HHs.

Subjects’ neutral temperature was predicted using three models. The neutral temperature from STSV regressed against operating temperature model showed relatively high operating temperature tolerance from HH1 occupants, with a neutral temperature of 30.9°C. HH2 occupants were less tolerant of their operating temperature, the evidence suggesting a neutral temperature 2.3°C less than for HH1 occupants. PMV regressed against the operating temperature showed a lower neutral temperature than the first model, namely, 26.5°C in HH1 and 25.4°C in HH2. Prediction using the optimum thermal comfort model with 90% acceptability produced a neutral temperature closer to the first model, namely, 29.8°C in HH1 and 29.8°C in HH2.

From these findings, it seems possible that thermal comfort is achievable in shaded naturally ventilated hostels with WWR of 0.35 where the internal-external relative humidity is above 70% RH, especially in south-facing rooms. Thermally neutral operating temperatures can increase up to 30.9°C in this particular room condition. It is also recommended that future research on thermal comfort using the PMV model include an indoor short-wave radiation parameter to predict better thermal comfort sensation for occupants living in a country with a hot and humid climate.

**References**


Evidence base prioritisation of indoor comfort perceptions in Malaysian typical multi-storey hostels

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ABSTRACT

This study focuses on assessing the effects of the indoor climate in typical multi-storey hostels in Malaysia on student occupants through objective, subjective and evidence based prioritisation measurements. The objective measurements consisted of operative temperature, daylight ratio, lighting level and indoor noise level. The subjective measurements were based on students’ thermal, visual, acoustic and overall indoor comfort votes. The prioritisation measurement using Multiple Linear Regression and Friedman test assessed the relationship between physical indoor thermal, visual, acoustic and indoor comfort perceptions. Findings suggest that subjective thermal ratings were significantly more reliable than objective measurements at predicting overall indoor comfort. Moreover, students living in hostel rooms with projected balconies were more satisfied with their indoor condition than the ones living in rooms without projected balconies. The results of this study also provide evidence that student occupants were more concerned with their thermal condition followed by acoustic comfort, and finally visual comfort.

1. Introduction

Malaysia is now experiencing a growth in the number of individuals attending colleges. Usman [11] reports that highest education enrollment in Malaysia is expected to provide for 266,000 places in more than 100 colleges in the year 2009. This scenario leads to the booming of multi-storey hostels in college campuses. However, not much building trend changes in room layout occurred since the 60s. Students stayed in shared accommodation with each other for one time. The hostel rooms are not en-suite and rarely designed with projected balconies. Rooms are also not air-conditioned but are compensated with ceiling fans.

Why do we need to assess the indoor comfort perceptions of student occupants staying in one-conditioned hostels is that as an earlier survey conducted, Dahlan et al. [2] observed that students living in non-air-conditioned university buildings in Malaysia were most likely to feel thermally uncomfortable in rooms without projected balconies through their thermal comfort FMV investigations. An investigation on perceptions of indoor environmental quality of high-rise residential buildings in Hong Kong found that thermal comfort was perceived as the most important indoor environmental quality attribute to its occupants subsequently followed by air cleanliness, colour and finally noise [3]. The same trend leads to the boom in the multi-storey hostels in college campuses. This scenario leads to the booming of multi-storey hostels in college campuses. However, not much building trend changes in room layout occurred since the 60s. Students stayed in shared accommodation with each other for one time. The hostel rooms are not en-suite and rarely designed with projected balconies. Rooms are also not air-conditioned but are compensated with ceiling fans.

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| Table 1 - Case study inventory. Case study buildings

<table>
<thead>
<tr>
<th>Building</th>
<th>1st Residential College, RMU</th>
<th>15th Residential College, LPM (96')</th>
<th>Miami Student Apartment, BINT (93')</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field measurement</td>
<td>20/06 (25.6 weeks)</td>
<td>27/06-25/07 (11 weeks)</td>
<td>24/06-10/06 (2 weeks)</td>
</tr>
<tr>
<td>Room Orientation</td>
<td>North &amp; South</td>
<td>South-east, south-west, north-east &amp; north-west</td>
<td>North-east, north-west</td>
</tr>
<tr>
<td>Room Dimensions</td>
<td>5.0 x 3.0 x 3.0 (m³)</td>
<td>4.3 x 3.0 x 3.0 (m³)</td>
<td>5.3 x 3.0 x 3.0 (m³)</td>
</tr>
<tr>
<td>Room Volume</td>
<td>43 m³</td>
<td>36 m³</td>
<td>34 m³</td>
</tr>
<tr>
<td>Floor Area</td>
<td>15 m²</td>
<td>16 m²</td>
<td>16 m²</td>
</tr>
<tr>
<td>Floor level</td>
<td>(including ground floor)</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Occupants' profile</td>
<td>Max: 2</td>
<td>Max: 3</td>
<td>Max: 4</td>
</tr>
<tr>
<td>Window Area</td>
<td>2.9 m²</td>
<td>3.2 m²</td>
<td>3.2 m²</td>
</tr>
<tr>
<td>Window to Wall Ratio</td>
<td>0.6</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Shading Ratio</td>
<td>0.3</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>Architectural Design</td>
<td>Adjustable Classy</td>
<td>Adjustable Classy</td>
<td>Adjustable Classy</td>
</tr>
<tr>
<td>Ceiling Reflectance Factor</td>
<td>0.7 (white paint)</td>
<td>0.7 (beige paint)</td>
<td>0.7 (beige paint)</td>
</tr>
<tr>
<td>Face of room</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Distance from highway</td>
<td>100 m</td>
<td>100 m</td>
<td>100 m</td>
</tr>
<tr>
<td>Roof finish</td>
<td>Ceiling render</td>
<td>Ceiling render</td>
<td>Ceiling render</td>
</tr>
<tr>
<td>Polyurethane</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Wall finish</td>
<td>0.6 (light blue paint)</td>
<td>0.7 (large paint)</td>
<td>0.7 (large paint)</td>
</tr>
<tr>
<td>Celling Reflectance Factor</td>
<td>0.7 (white paint)</td>
<td>0.7 (white paint)</td>
<td>0.7 (white paint)</td>
</tr>
</tbody>
</table>

Notes: 
(i.e. Masters Degree or PhD), Subjects' length of stay was indicated using four lengths, namely, less than a year; 2 years and 3 years and above. Daily wear clothing selection that ranges from 0.2 until 1.0 clo value were provided for subjects to choose. Clo values were estimated from ISO7730-16. Occupants were assumed to be most likely engaged with sedentary activities while in their rooms. Questions regarding student occupants' thermal, visual and acoustic sensations were based on three different periods of the day, namely, in the morning (8:00-11:10 am); afternoon (12:00-4:20 pm) and evening (4:30-7:00 pm). Questions were designed in HI and HI+ question along side with their values is written in parentheses as shown below.

<table>
<thead>
<tr>
<th>Question</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. How do you classify your thermal comfort? (cool, -3; hot, 3)</td>
<td>-3</td>
</tr>
<tr>
<td>2. How do you classify your room's brightness? (dark, -3; bright, 3)</td>
<td>3</td>
</tr>
<tr>
<td>3. How do you classify the exterior noise level heard in your room? (not noticeable, -3; annoying, 3)</td>
<td>3</td>
</tr>
<tr>
<td>4. Do you pull on the window curtain? (never: -3, to always: 3)</td>
<td>3</td>
</tr>
<tr>
<td>5. Questions concerning occupants' indoor condition influences and overall indoor comfort perception are indicated through the following questionnaires.</td>
<td></td>
</tr>
</tbody>
</table>

4.1. Objective measurements

4.1.1. Operative temperature measurements

Operative temperatures in H1, H2 and H3 at three different daytime periods were examined and presented in Table 3. All of the mean operative temperatures differed significantly beyond p < 0.01 level from one another with large effect sizes (i.e.: rjp > 0.14). The mean temperature differences among the three daytime periods in H1, H2 and H3 are from morning to evening (column of Table 3). This indicates that all three hostels show closer temperature variation in the morning but then gradually changing as the daytime progresses. Surprisingly, instead of presenting a lesser mean temperature difference in the evening, the result have revealed otherwise, because of a high mean temperature detected in H3 rooms.

Based on the case studies (row of Table 3), the largest mean difference is detected in H1 room and then followed by H2 and H1 rooms. H3 rooms show a large mean temperature difference between its morning and evening temperatures compared to other rooms, perhaps partially due to their larger room volume but small operable window to wall ratio, i.e., 0.2. This shows that H3 rooms were more likely to be warmer in the evening, whereas H1 and H2 rooms would probably receive more constant temperature distribution throughout the day.

It can be suggested that rooms that were shaded by projected balconies and long overhang roofs with shading ratio of 0.9 and 1.6, respectively, had operable windows to wall ratio of 0.1, and room volume below 50 m³ succeeded in passively controlling the operative temperature swings compared to un-shaded rooms. However, the mean operative temperatures for all 24 rooms do not differ significantly from each other, either shaded or not. Room orientation also has little effect towards the mean operative temperature.

4.1.2. Daylight ratio measurements

Daylight ratio for the measured rooms was calculated based on Equation (2):

\[
D_{daylight} = \frac{I_{in}}{I_{out}} \times 100
\]

Table 4 presents the mean daylight ratios for rooms in H1, H2 and H3 during three periods. In each daytime period (column of Table 4), mean daylight ratio recorded showed significant difference beyond p < 0.01 level with large size effects (i.e.: rjp > 0.14) among hostels. This measurement shows daylight ratios that were in compliance with the minimum daylight factor provided by CIBSE [18], namely above 0.5% for a multi-purpose room. However, rooms in H2, especially the ones facing North-west and North-east were out, namely above 2% of daylight ratio, which exceed the average daylight factor for domestic application [18]. The daylight ratio recorded for these H2 rooms were higher than rooms in H3 that were also in line in volume.

Mean daylight ratio difference for each period was widest in the morning, and descends as the day progresses, based on the decreasing external horizontal and vertical illuminance throughout the day. In all cases, room H1 presented the least daylight ratio compared to the other rooms during all three periods.

In each case study hostel (row of Table 4), medium size effect and mean differences in daylight ratio were detected in H1 and H3 rooms, while H2 rooms show an even smaller effect size (i.e.: rjp < 0.06). This suggests that the daylight ratio in each hostel room varied from 0.5% up to 7.5% differed significantly with very small daylight ratio variation. Higher daylight ratio was observed in H1 hostel rooms at 0% and 5.9% differed significantly with indoor surface reflectance factor.

4.1.3. Sound pressure level measurements

Results from the ANOVA repeated measures that observed mean variation between hostels and daytime periods is recorded in Table 5. The indoor noise level in each hostel showed significantly beyond p < 0.01 in the morning, afternoon and evening columns of Table 5. This indicates that the noise level in the hostels-orientated from H2, H1 and finally H3. However, indoor noise level show very small indoor noise level differences throughout the day in each hostel (row of Table 5). This partially indicates that the farther distance from highway, like in case of H2, predominantly controls the indoor noise level.

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4.2. Subjective measurements

4.2.1. Thermal, visual and acoustic comfort votes

Subjective measurements design in rooms with balconies, like in case of HI. Heat production rate for the student occupants was estimated to be between 60 W (i.e., when sleeping) and 140 W (i.e., studying and other sedentary activities) (9,10).

Thermal comfort votes throughout the day in the morning (8:00-11:59 am), afternoon (12:00-2:59 pm) and evening (3:00-5:59 pm) are shown in Table 6. According to daytime periods (column of Table 6), occupants felt that their rooms were slightly cooler in the morning (point: -0.1), slightly warmer in the afternoon (point: 0.1) and neither warm nor cold in the evening (point: 0) except for the study occupants where their votes in the evening, occupied by 0.7. However, even though their rooms are slightly warm but decrease in intensity (point: 0.7). Votes in each daytime period varied with medium size effects (η² = 0.14) indicating that occupants in those hostels show almost identical thermal comfort responses.

In each hostel (row of Table 6), the mean vote show a large size effect (η² = 0.14) among the daytime periods. This indicates that occupants perceived different thermal sensation for morning, afternoon and evening which comply with the objective measurements. Objective measurements conducted in the hostels during these three periods show temperature increase of about 1.0°C from morning to afternoon. But three different effects between the hostel periods and the mean temperature namely, temperature decrease of 0.6°C in HI; no temperature difference in H2; and temperature increase of 0.6°C in H3. Out of the three hostels, HI rooms are perceived to have the lowest in room temperature in every period, thus suggesting that occupants are slightly more thermally comfortable in shaded indoor condition and vice versa.

Visual comfort votes collected from occupants in three case study hostels are shown in Table 7. Out of the three daytime periods, mean visual comfort votes ranged from 0.6 to 0.7 only during the afternoon (column of Table 7). This shows that occupants were more aware of the impact of glare in the afternoon compared to in the morning and evening and despite any fenestration features. This was because large flared of sunlight (as observed in both H2 and H3) was used when the sunlight was reflected in the rooms during the afternoon and was considered to cause not only glare discomfort but also heat gain.

Occupants' votes in Table 7 also reveal their pattern of expectation towards the daylighting condition from morning to evening (see column of Table 7). It shows that occupants, regardless of their hostel express similar visual comfort vote for morning and evening, which usually fall between point 'neutral' and 'slightly lit'. In the afternoon, all occupants voted that their rooms were usually quite bright (point: 1.5-2.0).

Table 8 shows acoustic comfort votes in the morning (8:00-11:59 am), afternoon (12:00-2:59 pm) and evening (3:00-5:59 pm) collected from occupants in HI, H2 and H3. The medium size effect (η² = 0.14) in Table 8 indicates that occupants' acoustic comfort votes remain constant throughout the day (column and row of Table 8). Through this finding, it can be suggested that occupants have adapted to the level of noise available indoors and find the condition neither noisy nor quiet during the daytime despite indoor noise level changes recorded.

4.2.2. Student occupants' overall indoor climate satisfaction votes

Previous studies reported that even though H2 room's lowest overall operative temperature, its thermal comfort vote indicates that occupants are more likely to be associated with thermal comfort, hence also affects the overall indoor climate satisfaction.

4.3. Prioritisation of indoor conditions based on the student indoor comfort perceptions

The mean ranks for the occupants' indoor comfort perceptions are shown in Table 10 for H1, H2 and H3 occupants, respectively. Descending sequential order of the indoor conditions as ranked by occupants is shown in parenthesis next to each mean rank. It is considered the most influential indoor condition, while T is the weakest. The mean ranks in each hostel show significant mean difference beyond p < 0.01 between the indoor conditions. Rank difference level in HI (i.e.: x² = 20.0) indicates that ranks between the indoor conditions show closer degree of difference than ranks in H2 (x² = 6.2) and H3 (x² = 2.00).

In HI, occupants' indoor comfort is strongly affected by evening indoor air temperature, sunlight heat, glare, room humidity and finally by daylighting. It can be assumed that, because HI rooms are perceived to be slightly cooler than the two other hostels, there could be no agreement with their indoor thermal conditions, but show slightly higher annoyance to external noise. Observation from Table 10 also confirms that occupants in HI are less worried about their daylighting condition, even though the rooms are dimmer than the other hostel rooms (Table 4).

There is a close resemblance of indoor comfort ranks from occupants in H2 and H3. In H2 occupants' indoor comfort is significantly affected by summer outdoor noise, glare, room airiness, adequate daylighting and room humidity. Occupants in H3 also rank the air temperature to be the most important indoor condition, followed by sunlight heat, external noise, room airiness, adequate daylighting, room humidity and finally glare. H2 and H3 occupants' ranks clearly show that they are strongly affected by their rooms' indoor thermal condition, natural lighting and daylighting. It can be interpreted that occupants in both hostels also show less interest in daylighting, room humidity and glare.

5. Discussions and findings

Objective and subjective measurements that assess indoor thermal, visual and noise conditions were successfully conducted in three typical multi-storey hostels in Kuala Lumpur, Malaysia. The results reported reflect the particular hot climate conditions with not much seasonal variation. This condition is inherent in the hostel rooms during both objective and subjective measurements.

In terms of the student occupants' thermal responses, it can be concluded that they are acclimatised with their indoor condition provided that the indoor operative temperature is below 30°C. Cooling strategies such as, switching on fans and opening windows are normally acceptable to the student occupants staying in Malaysian typical multi-storey hostels. Moreover, additional studies through projected balconies at the window wall help to create a cooler environment focused on the survey votes gathered from student occupants in HI.

Findings indicate that occupants visually expected that their naturally lit room to be dim (i.e.: as monitored in H1), when the Daylight Ratio is below 0.8. Moreover, occupants perceived their naturally lit rooms to be bright (i.e.: as monitored in H2) when the Daylight Ratio is above 2.0. Even though, in the rooms in HI are dimmer than the other hostel rooms, their Daylight Ratios are just within the minimum standard recommended by BBR, namely 0.5.

Findings from acoustic comfort assessment found that indoor noise level is affected by the distance of their noise source. Both H2 and H3 rooms had the least indoor noise level because the hostel was located farther compared to HI and H3. Despite its close distance from the highway, rooms in H1 have low indoor noise levels (i.e.: <55 dBA), perhaps because their windows were not facing the highway and did not receive any prevailing wind. Furthermore, it could be supposed that balcony outside the room screens the traffic noise from entering. According to the survey, occupants have adapted to the level of noise available indoors and the condition neither noisy nor quiet.

The study assumptions made, it can be proposed that rooms that are shaded via projected balconies with opaque railing (i.e.; concrete) are considered more successful compared to the level of Daylight and indoor noise level, not the operative temperature entirely. On the other hand, rooms without this design feature show a better indoor climate satisfaction on overall indoor indoor comfort votes, satisfactory. Based on their overall indoor climate satisfaction votes, it suggested that occupants are tolerant with the indoor climate of

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Do you pull the curtain on a Clear Day? (H1)

Table 8

<table>
<thead>
<tr>
<th>Case</th>
<th>Morning 8:00-11:59 am</th>
<th>Afternoon 12:00-5:59 pm</th>
<th>Evening 6:00-9:59 pm</th>
<th>H2</th>
<th>H3 (n = 90)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1</td>
<td>Mean ± Std Dev</td>
<td>Mean ± Std Dev</td>
<td>Mean ± Std Dev</td>
<td>0.4</td>
<td>0.19 ± 0.11</td>
</tr>
<tr>
<td>H2</td>
<td>Mean ± Std Dev</td>
<td>Mean ± Std Dev</td>
<td>Mean ± Std Dev</td>
<td>0.3</td>
<td>0.16 ± 0.10</td>
</tr>
<tr>
<td>H3</td>
<td>Mean ± Std Dev</td>
<td>Mean ± Std Dev</td>
<td>Mean ± Std Dev</td>
<td>0.2</td>
<td>0.13 ± 0.09</td>
</tr>
</tbody>
</table>

Table 9

<table>
<thead>
<tr>
<th>Overall indoor climate satisfaction</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean ± Std Dev</td>
<td>0.9</td>
<td>0.8</td>
<td>0.7</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Table 10

<table>
<thead>
<tr>
<th>Indoor Conditions</th>
<th>Mean Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1</td>
<td>H2</td>
</tr>
<tr>
<td>Indoor air temperature</td>
<td>4.45 (6)</td>
</tr>
<tr>
<td>Humidity condition</td>
<td>4.58 (7)</td>
</tr>
<tr>
<td>White light height</td>
<td>3.08 (4)</td>
</tr>
<tr>
<td>Adequate daylighting</td>
<td>3.06 (4)</td>
</tr>
<tr>
<td>Average air noise</td>
<td>4.50 (7)</td>
</tr>
</tbody>
</table>

Fig. 1. Do you pull the curtain on a Clear Day? (a) H1; (b) H2; (c) H3. Never (-3) to Always (3).

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References

[1] Uthman, 361:00 to 70.00. A day climatic value for 260.00 places in higher region will be provided within this year. In: Uthman 2009. (M., Djhafra).


Abstract

Conventional tropical building designs are experiencing new paradigm in its environmental response to improve lighting ambiance and occupants' visual comfort through the exploitation of daylighting. However, it is important for architects to understand that flaws in daylighting strategies could lead to disadvantages such as, hinder vision, cause discomfort, increase interior heat gain and demands excessive energy. The objective of this study is to assess how occupants' perceived their visual condition through daylight ratio and luminance level measurements. Measurements were conducted throughout a two months period starting from 12th May until 3rd July 2007. Three case studies consisted of typical Malaysian hostels located in Klang Valley, were selected namely, Twelfth Residential College, Universiti Malaya (H1); Eleventh Residential College, Universiti Putra Malaysia (H2); and Mumi Student Apartment, Universiti Tenaga Nasional (H3). Daylighting source in all these case studies were from side-lit windows. In overall, findings suggested that occupants were at ease with the level of daylighting available in their rooms even though rooms that were shaded by projected balconies (i.e.: H1) were dimmer than the rooms that were not shaded (i.e.: H2 and H3).

Keywords: Daylight ratio; luminance; objective measurement; subjective measurement; illumination; visual comfort; side-lit window.

1.0 Introduction

The use of daylighting was common to building designs throughout recorded history. However, in the 1950s fluorescent lighting, air-conditioning and other electricity usage were combined to make a new commercial building paradigm, thus reducing daylighting implementation [1]. The application of daylighting in building has been proven to increase social, environmental and economic performances compared to standard construction with only artificial lighting. Several studies [2-7] suggested that daylighting implementation in tropical buildings could optimize the lighting ambiance and reduces glare discomfort. Daylighting strategies can be achieved through top-lit and side-lit apertures. Study in the effects of atrium suggested that side-lit apertures provided more stable daylighting illuminance into the interior as compared to top-lit daylighting sources [6].

Unfortunately, daylighting practice is still not a priority in Malaysia. Buildings erected from the early 60s until the 90s were designed without any climatic adaptation to local climate. In the case of office and commercial buildings, large glazing areas adapted from international style design were collaborated into buildings disregarding Malaysia’s high sky irradiance factor that contributed to visual discomfort and higher cooling load.
Malaysian sky type has been identified as intermediate sky (i.e., average cloudy condition with cloud cover value of 6 to 7 oktas). Moreover, the Malaysian daylight design criteria is within ten to eighty klx during working hours from 8 am to 5 pm. The total percentage of external illumination in Malaysia that falls above ten klx during working hours is 93% [3, 8]. This suggests that the possibility to implement daylighting in buildings in Malaysia is very high.

The daylight ratio is used in obtaining the percentage ratio of internal illumination level with its simultaneous external illumination level. This type of measurement is viable in countries close to the equator, like Malaysia because the sun shines straight overhead in the afternoon most of the year with noon sun angles of 66.5° (June solstice) to 113.5° (December solstice) [9]. The high sun angles contribute to intense external illumination level throughout the year.

Moreover, in hot-humid climates, the sky is typically overcast and its luminance is often above 7000 cd/m², which results in very bright proportion of diffused radiation when viewed from a moderately lit room. Due to this condition, it is meaningless to calculate the interior lighting in photometric illumination terms. Therefore daylight condition is measured using the ratio of the internal illumination to the simultaneous external illumination, which can be taken as a constant [10, 11]. This constant ratio is expressed as a percentage as shown in Equation 1:

\[
\text{Daylight Ratio} = \frac{\text{internal illumination}}{\text{external illumination}} \times 100
\]  

In the present study, the daylight ratio and luminance of window level were measured in three hostels in Klang Valley, Malaysia. These measurements were conducted throughout a two months period starting from 12th May until 3rd July 2007. The hostels were namely, Twelfth Residential College, Universiti Malaya (H1); Eleventh Residential College, Universiti Putra Malaysia (H2); and Mumi Student Apartment, Universiti Tenaga Nasional (H3). In addition, questionnaire surveys were administered to identify occupants' visual comfort perceptions. It is hoped that the results can provide useful information on the application of daylighting in future high-rise development in tropical countries.

2.0 Methodologies

Data collection duration began in May 7 until July 19, 2007, with a total of 78 working days. Information about the buildings was gathered starting from May 7 until May 11. The field measurement started with H1 for two weeks (i.e.: May 12 until May 25), H2 for four weeks (i.e.: May 27 until June 23) and H3 for two weeks (i.e.: June 24 until July 6). The questionnaire surveys were administered during the two following remaining weeks.

2.1 Determining weather type (i.e.: either Overcast or Clear Days)

In this study, the case studies were selected at locations with high ratio amount of sky view factor when captured using Nikon CoolPix 950 digital camera fitted with a Nikon FC-E8 fisheye lens. Sky view factor at the particular locations were observed to be between the ranges of 0.9 to 1.0, where, the value ‘1’ shows no foliage or obstruction visible in the photograph. The estimation of the sky view factor for the locations were made based on common observations conducted [12-15].
In order to identify the relationship between outdoor and indoor microclimate, the weather condition and cloud patterns determined by fisheye images of the case study locations were monitored. Cloud patterns were monitored four times a day, namely at 8:00 a.m., 12:00 p.m., 3:00 p.m., and 5:00 p.m. based on sky condition images captured. ‘Overcast Day’ was determined based on thin to heavy cloud conditions while ‘Clear Day’ was determined based on clear sky with none to very thin cloud distribution.

2.2 Objective measurements

Each room orientation was measured for three days at three different vertical room locations simultaneously. The procedures for both of these investigations were conducting in eight steps. (1) Two ISO TECH lux meters were used in this investigation, namely, for outdoor and indoor purposes. (2) Readings were taken six times per hour with 15 minutes interval between the vertical room locations. (3) For indoor purpose, the lux meter was located 2.0m distance form window and mounted 0.8m above the floor on a tripod. Windows were left exposed with no curtain. (4) 180° view of the room was captured using a fisheye lens camera. (5) Simultaneously, the second lux meter was mounted 1.5m from the ground on a tripod in the middle of an open field close to the case study building. (6) Glare measurements were taken horizontally using Hagner photometer 2.0m from the window and 1.0m from the floor. (7) Field of view was 40° in altitude and 90° in azimuth so that it would be measuring the mean luminance in a horizontal 40° band [16] (Figure 1). This particular band was suggested as suitable in determining occupant’s visual lightness and interest. (8) Readings for luminance measurement were also recorded six times per hour with 15 minutes interval between the vertical room locations.

2.3 Subjective measurements

Subjective measurement was conducted using questionnaire survey. To aid subjects, the questionnaire was prepared with Bahasa Malaysia translation and glossary of comfort terminologies. Only college aged female students were approached. The restriction in the sample collection was due to hostel regulation that prohibits female student or researcher to enter male hostel compound and vice versa. Table 1 shows the description of visual comfort questions used in the questionnaire survey.

2.4 Statistical Analyses

Statistical Package for Social Sciences (SPSS) version 12.0 was used to analyse results in this study. The statistical analysis applied in this research was analysis of variance (ANOVA) with Two-tailed Significant Test. It is an inferential statistics test used to determine whether an independent variable has had a statistically significant effect on a dependent variable. In a repeated measures, each case or subject experience every condition of the assessments. Information that can be delivered from this analysis is to locate more specifically the sources of systematic variation in the assessments through comparing the means [17].

Furthermore, it is often useful to know not only whether an experiment has a statistically significant effect, but also the size of any observed effects. The effect size is also known as partial eta-squared, \( \eta_p^2 \), which estimates the degree of association for the sample, where

\[
\eta_p^2 = \frac{SS \text{ treatment}}{SS \text{ treatment} + SS \text{ error}}
\]
The effect size as shown in Equation 2 is expressed by the variance of the sums of squares for a particular effect (SS treatment) from the sum of squares of that effect plus the error sum of squares (SS error). The partial eta squared is used instead of the complete eta squared because the author prefers to treat the value as a proportion from 0 to 1. The usual benchmarks for classifying the value of η_p^2 are represented in Table 2 [18].

3.0 Measure room specifications

Specifications and location of sensors in measured rooms are shown in Figures 2 and 3. Figure 4 shows the elevations and locations of measured rooms in the three selected hostels. Daylighting source in all these case studies were from side-lit windows. Rooms in H1 were the only rooms with projected balcony adjacent to their window walls.

Measured rooms in block C and D of H1 were chosen at the 1st, 5th and 9th floor (top floor) and were vertically aligned. Rooms here were facing north and south. The reflectance factor for walls, floor and ceiling were 0.6, 0.3 and 0.7, respectively [19]. Measured rooms in H2 were selected at 1st, 5th and 7th floor (top floor) facing north-east, south-east, north-west and south-west. The reflectance factor for walls, floor and ceiling were 0.7, 0.3 and 0.7, respectively [19]. Measured areas in H3 were selected at 1st, 5th and 10th floor (top floor) facing north and west. The reflectance factor for walls, floor and ceiling were 0.7, 0.6 and 0.7, respectively [19].

4.0 Results

4.1 Objective visual measurements

4.1.1 External and internal horizontal illumination

External and internal horizontal illumination data were used to estimate daylight ratio available in measured rooms. Table 3 provides a summary of the external illumination collected during measurement periods. In overall, the mean external horizontal illumination measured is about 50 Klx.

Indication of Overcast and Clear Days is shown in Table 4. Throughout the measurement period, there were 13 and 11 days identified as Overcast and Clear Days, respectively. External horizontal illumination in Clear Day is about 6 Klx lower than Rainy Day (Table 5). The difference in sky illumination shown is a result of the clouds influence as the albedo in absorbing and reflecting of solar radiation. Through the observation, it seems that the Overcast Days with thin bright clouds received twofold of external illumination sources, namely, from the direct and reflected sunlight. However, during Clear Days, the external illumination source only comes from direct sunlight.

Internal illumination was measured in 24 naturally lit rooms in typical Malaysian hostels. Table 6 shows the summary of result measured at three different vertical rooms located at first, fifth and top (7th, 9th, or 10th) floors in H1, H2, and H3. Internal horizontal illumination distribution in overall is lower and more constant at the higher floors, i.e.: 9th and 10th floor compared to room located seventh floor and below. North-West oriented rooms in H2 display the highest mean illumination of 1880 Klx, 2007 Klx and 1954 Klx for first, fifth and seventh floor rooms.
respectively. Meanwhile the lowest mean illumination is measured in H1 South rooms, namely, 336 Klx, 405 Klx and 137 Klx for first, fifth and ninth floor rooms, respectively.

These findings indicate that rooms facing north-west and un-shaded received high amount of illumination transmittance, despite a relatively low mean external horizontal illumination level recorded (Table 3). Moreover, rooms facing south and shaded received low illumination levels even though the external horizontal illumination measured was relatively high (Table 3).

4.1.2 Daylight Ratio measurements

Daylight Ratio for the measured rooms was calculated based on Equation 1. Table 7 shows the statistical summary for Daylight Ratio at three different vertical room locations in H1, H2 and H3. In sum, most of the measured rooms show daylight ratios that are in compliance the minimum daylight factor provided by CIBSE [20], namely above 0.5 % for a multi-purpose room.

On the other hand, rooms in H2, especially the ones facing North-west and North-east were over lit, namely above 2 % of Daylight Ratio, which exceed the average daylight factor for domestic application [20]. The daylight ratio recorded for these H2 rooms was higher than rooms in H3 that were also larger in volume. In order to understand the daylighting behaviour of the measured rooms, tests on the Daylight ratio during different weather types and daytime periods were conducted.

An observation of mean daylight ratio at different vertical room location is shown in Figure 5. Lower and middle floor rooms are located at 3m and 15m above ground, respectively. Meanwhile rooms on top floors of H1, H2 and H3 are measured at 27m, 21m and 30m above ground, respectively. As expected, shaded rooms in H1 obtained the lowest daylight ratio than un-shaded rooms in H2 and H3.

In terms of daylight ratio pattern, it can be observed that daylight ratio increases up until a certain altitude, namely 21m (i.e.: rooms on top floor of H2), but decreases as the vertical room location increases further (i.e.: rooms on top floor of H1 and H3). Obstructions such as trees and other low-rise structure were not available at 15m above ground thus enabling daylight level to increase in rooms at this particular floor level. The reduction of daylight ratio in rooms above 21m above ground could have been influenced by lack of incidental daylight from other reflective sources.

Figure 6 shows the daylight ratio collected at different room orientations in H1, H2 and H3. Each room orientation has three measured rooms. As expected, shaded rooms received the lowest daylight ratio than un-shaded rooms (Figure 6a). North-west oriented un-shaded rooms in H2 are exposed to the highest daylight ratio, despite its relatively low external horizontal illumination (Table 3). In H3, North-facing rooms received more daylight than west facing rooms because the former room orientation was exposed to more external horizontal illumination than the latter room orientation (Table 3).
In further examining the effects of shading strategy to Daylight Ratio during two common weather types in Malaysia, an ANOVA repeated measures are conducted. Table 8 summaries the daylight ratio received during Overcast and Clear Days in the case study hotels. The daylight ratio during Overcast and Clear Days received by H1, H2 and H3 show very strong significance difference \( p < 0.01 \) with larger size effects of above 0.14 (column of Table 8). Mean daylight ratios recorded in Clear Day differed wider than in Overcast Day. Daylight level received in rooms ascended from H1, followed by H2 and finally H3 for each weather type. This is because H1 rooms are shaded while the other rooms are not. H3 rooms received more daylight ratio than H2 rooms partially because the floor reflectance factor in the former hostel was higher, namely, 0.6.

Moreover, very small mean differences are detected between Overcast and Clear Days in H1, H2 and H3 (row of Table 8). This suggests that weather has no clear influence over the daylight level of a room. Therefore, it can be partially concluded that the window to wall ratio, shading ratio and indoor surface reflectance factor are more important in controlling daylight ratio compared to weather conditions. In terms of daylighting condition in rooms, despite receiving the lowest daylight ratio compared to other rooms, the mean daylight ratio for rooms in H1 during Overcast and Clear Days are above the minimum daylight factor recommended by CIBSE [22], thus indicating that shaded rooms in H1 succeeded in providing sufficient daylighting regardless of weather condition.

Furthermore, daylight ratio received in rooms is break down according to three different daytime periods, namely, morning (8:00 am to 11:59 am), afternoon (12:00 pm to 2:59 pm) and evening (3:00 pm to 5:59 pm). Table 9 presents the mean daylight ratios for rooms in H1, H2 and H3 during those periods. In each daytime period (column of Table 9), mean daylight ratio recorded show significant mean difference beyond \( p < 0.01 \) level with large size effects \( \eta_p^2 > 0.14 \) among the hostels. As expected, the level of daylight ratio mean difference for each period is widest in the morning, and descends as the day progresses, which is based on the decreasing external horizontal illumination in the evening. In this test, it still shows that rooms in H1 presents the least (but sufficient daylight ratio) compared to the other rooms during all three daytime periods.

In each case study hostel (row of Table 9), medium size effects \( \eta_p^2 < 0.14 \) of mean differences are detected in H1 and H2 rooms, while H3 rooms show an even smaller size effect \( \eta_p^2 < 0.06 \). This suggests that the daylight ratio in each case from 8:00 am until 5:59 pm show little difference. Higher daylight ratio is evidence in the evening, which resulted from decrease in the denominator (i.e.: external illumination) in the estimation of the daylight ratio model (Equation 1). Therefore it is somewhat evidenced that despite diurnal changes observed throughout the daytime, the window to wall ratio, shading ratio and indoor surface reflectance factor provide a stronger influence to daylight ratio in these rooms.

4.1.3 Hourly Luminance of window

Table 10 and Figure 7 present the luminance of window measured in 24 naturally lit hostels rooms in H1, H2 and H3. In overall, the luminance level increase as the vertical room location increases.
Cross-examinations between Figure 6 and 8 found that luminance level has an inverse relationship with daylight ratio as observed in H1 and H2. However, in H3, luminance level increases in accordance to daylight ratio. The condition in H3 rooms could be partially influenced by window to wall ratio (WWR). Higher WWR of 0.4 in H3 rooms than in H2 (i.e.: WWR = 0.2) enable more luminance of window to be available in the former hostel.

Mean luminance from the window during Overcast and Clear Day is shown in Table 11. Although differed significantly beyond at least $p<0.05$ level, the means are not widely distributed in among the weather types (column of Table 11) and case study hostels (row of Table 11). This indicates that neither fenestration features (i.e.: window to wall and shading ratio) nor weather types show clear influence towards the luminance measured.

Investigation on luminance of window in the morning, afternoon and evening is summarized in Table 12. It can be observed that the highest level of luminance is measured in the afternoon for all three hostels.

4.2 Subjective visual measurements

298 female college-aged students living in H1, H2 and H3 took part in this survey.

4.2.1 Visual comfort: rainy and clear days

Table 13 summarized the visual comfort votes on Overcast and Clear Days collected from occupants in H1, H2 and H3. Occupants participated in the subjective survey in H1, H2 and H3 were 100, 108, and 90 persons, respectively. In reference to results presented in row of Table 13, it seems that occupants in H2 were more sensitive to their visual comfort during Overcast Day; meanwhile occupants in H3 were more sensitive during Clear Day.

Occupants in H1 however, show moderate votes for both weather conditions. Visual comfort votes between Overcast and Clear Days widely differed with large effect size above 0.14 from each other. This indicates that occupants’ visual comfort votes regardless of window size and room volume (column of Table 13), are strongly influenced by the weather condition. On the contrary, no significant mean Daylight Ratio differences were detected between Overcast and Clear Days (Table 8). Occupants could have based their visual comfort perception on the availability of luminance from the window instead. This is because the luminance level recorded between Overcast and Clear Days show significant mean differences even though with medium and sometime small size effects (Table 11).

Occupants were further asked regarding the adequacy of daylighting in illuminating their rooms during Overcast and Clear Days. Figure 9 illustrates the vote distribution sampled from H1, H2 and H3. In H1, 31% of occupants expressed that the daylighting condition in their rooms during Overcast Day were quite inadequate (Figure 9a). Their mean votes shifted from -0.6 to 1.2 when asked regarding their daylighting availability in Clear Day (Figure 9b). The vote distributions in H3 (Figures 9e and 9f) show quite a resemblance to the one sampled in H1 in both Overcast and Clear Days.
However, occupants in H2 experienced high levels of daylighting availability in both Overcast and Clear Days (Figure 9c and 9d). From these vote distributions, it can be concluded that rooms in H2 are brightly lit through daylighting despite any weather conditions. Meanwhile rooms in H1 are perceived to be the dimmest in both Overcast and Clear Days.

Figure 10 represents occupants’ satisfaction votes with the daylighting condition in their rooms. As expected, occupants in H1 are least satisfied with the daylighting condition with mean vote of 0.9. The highest level of satisfaction is shown in H3. Findings confirmed that rooms in H1 are not only dimmer but also have the least visual comfort vote compared to other rooms.

4.2.2 Visual comfort: daytime period

Summary of mean for visual comfort votes in the morning (8:00 – 11:59 a.m.), afternoon (12:00 – 2:59 p.m.) and evening (3:00 – 5:59 p.m.) collected from occupants in three case study hostels is shown in Table 14. Out of the three daytime periods, mean visual comfort differed significantly beyond p<0.01 only during the afternoon (column of Table 14). This show that occupants were more aware of the impact of glare in the afternoon compared to in the morning and evening and despite any fenestration features. This was because large floods of sunlight (as observed in H2 and H3) was usually evidenced in the floor of their rooms in the afternoon and was considered to cause not only glare discomforts but also heat gain.

Occupants’ votes in Table 14 also reveal their pattern of expectation towards the daylighting condition from morning to evening (row of Table 14). It shows that occupants, regardless of their hostel, express similar visual comfort vote for morning and evening, which usually fall between point ‘neutral’ and ‘slightly lit’. In the afternoon, all occupants voted that their rooms were usually quite bright (point: 1.5 to 2.0).

4.2.3 Visual comfort: window function

Results from investigation on whether occupants are in content with the size of their window’s aperture in allowing daylighting are illustrated in Figures 11a to c. Mean votes ascended from H1, H2 and H3 with means of 1.0, 1.6 and 1.7, respectively. This indicates that occupants in overall show satisfactory agreement that the window allow adequate daylighting into their room. However, a few occupants in H1 show less satisfactory vote, because their rooms were dimmer than the other hostel rooms. 73% and 78% of occupants in H2 and H3 respectively voted above the neutral point (point = 0), however only 60% of occupants in H1 fall into this category.

To cross-examine whether the daylighting performance in hostel rooms were not deprived by curtain usage throughout the day, occupants were asked whether or not they pull the curtain during Clear Day. It was assumed that occupants perceived the daylight transmittance to be higher in Clear Day compared to Overcast Day, thus provide better daylighting source compared to during the latter weather condition. In other words, occupants were most likely to switch on artificial lighting during Rainy Day. The least vote with mean value of -0.1 is found in H1, which indicates that its occupants hardly pull their curtain during Clear Day. On the contrary, the average of occupants in H2 and H3 voted that they quite regularly (point: 1.0) pull the curtain on Clear Day.
The responses shown could be related to luminance level availability during Clear Days (Tables 12). Votes in H1 suggested that its occupants' reaction in rarely using the curtain was because they perceived their rooms to receive low luminance levels; hence, more daylighting is required from the outside. While occupants in H2 and H3 perceived the opposite out of the indoor visual condition of their rooms. Correlation between occupant's curtain usage vote and glare tolerance vote during Clear Day is shown in Table 15. From the observation, it shows that occupants staying in H2 rooms have the highest correlation value, i.e. beyond \( p < 0.01 \) level, than the other two hostels. The significant relationship was perhaps being influenced by the fact that rooms in H2 had higher glare availability (point: 0.7) than in H1 and H3. Therefore, it can be suggested the more intense the glare condition indoors, the higher the curtain usage will be.

However, the usage of artificial lights not was favored even though most of the occupants prefer to pull their window curtain during Clear Day. Occupants from all three hostels expressed that they rarely switch on the artificial lights during Clear Day (Table 16). Votes from H1 occupants verify that even though their rooms were perceived to be dimmer compare to in H2 and H3 in Clear Day, occupants here were satisfied with the visual condition in their rooms (Table 16). Even though, strong negative correlation value was identified, but not much variation of mean artificial lighting usage was detected among the three hostels.

Based on the votes collected, the occupants' visual expectations can be estimated to be influenced by certain daylight ratios and luminance level. Findings indicated that occupants' visually expected that their naturally lit room to be dim (i.e.: as monitored in H1) when the daylight ratio and luminance were 0.8% and 1482 cd/m\(^2\), respectively. Moreover, occupants' perceived their naturally lit room to be bright (i.e.: as monitored in H2 and H3) when the daylight ratio and luminance reached 2.3% and 2146 cd/m\(^2\), respectively.

5.0 Discussions and findings

Findings are discussed based on the assumptions given below:

1. **Daylight Ratio increases in accordance to building altitude.**

   Finding obtained is in contrast with this assumption. daylight ratio measured although rises in accordance to floor level, but later show deterioration once reaching over 27m above ground (Figure 5). This could be resulted from lack of incident daylighting source, which increases daylight ratio in opposite building, however not many literature support this notion [21, 22].

2. **Suitable window to wall ratio (WWR) provides sufficient daylight transmittance indoors.**

   Throughout the assessments, rooms in H1 with WWR of 0.6 and shading ratio from 0.9 to 1.6 are shown adequate daylight ratio as recommended by CIBSE [22] for small size hostels room of 45m\(^3\). Rooms in H2 however received excessive daylight ratio especially the ones facing north-east and north-west. This partially suggest that small rooms (i.e: 48m\(^3\)) with WWR of 0.2 and un-shaded tend to be very bright. It is also suggested that because the width and depth of rooms in H2 are almost similar, could be the cause of the high daylight level detected which is also in agreements with finding by Ghisi and Tinker [23].
3. Outdoor condition such as weather and external illumination determine the Daylight Ratio availability.

Daylight Ratio show either no or small significant difference with both weather type (Table 7) and external illumination (Table 8).

4. Outdoor condition such as weather and external illumination influence occupants' visual comfort.

Findings shown suggested that occupant's curtain usage is influenced by the amount of luminance of window. Shaded rooms such as founding H1 were rarely covered by curtains because occupant perceived the interior to be dim. Meanwhile, more frequent curtain usage were recorded in H2 and H3. However, occupants in all the rooms rarely switched on the artificial lights during Clear Day even the ones staying in H1. This shows that window curtain usage is likely to be influenced by luminance of window, where it is used to offset glare and heat during clear days. Meanwhile the usage of artificial lighting is being used to equalize low external illuminance and is rarely switched on in clear day. The findings are in good agreements with findings from Nicol et al and Begemann et al [24, 25].

5. Occupants have innate visual expectations toward their indoor surrounding.

Findings indicate that occupants' visually expected that their naturally lit room to be dim (i.e.: as monitored in H1) when the daylight ratio and luminance are 0.8% and 1482 cd/m², respectively. Moreover, occupants' perceived their naturally lit room to be bright (i.e.: as monitored in H2 and H3) when the daylight ratio and luminance reach and above 2.3% and 2146 cd/m², respectively.

6. Occupants' visual discomfort is not influenced by the window size.

Findings suggested that visual comfort is more dependent on outdoor conditions, such as, weather (Table 13) and external illumination changes throughout the daytime (Table 14) than window size. This notion is suggest through observation in Figure 8, where all occupants expressed satisfactory agreement that their window size allows adequate daylighting to occur. However, unlike H1 occupants, H2 and H3 occupants showed more degree of satisfaction with their window size. It could be considered that the level of brightness influenced by external illumination level in a room triggers the occupants' reaction to window size. This finding is in good agreement with findings from [26, 27].

Conclusions

This paper discussed the relationship between the objective and subjective aspects of lighting purposes in typical hostels in Malaysia. In overall, occupants were at ease with the level of daylighting available in their rooms even though some of the rooms were dimmer because shaded by projected balcony that was adjacent to the window wall than the un-shaded rooms.

The authors recommended that more studies on identifying the relative threshold of occupant's dim and brightness expectations. In this study, similar identifications are made through the observation of curtain and artificial lighting usage.
References

1. Ternoczy, S.E., Daylighting every building. 1999. Daylighting Collaborative: Energy Center of Winconsin. LightForms LLC.
6. Ahmad, M., H., The Influence of Roof Form and Interior Cross Section on Daylighting in Atrium Spaces in Malaysia. 1996, University of Manchester, UK.
9. Pidwimy, P., Daylighting Collaborative: Energy Center of Wisconsin. LightForms LLC.
Figure 1: Schematic diagram of horizontal 40° view band

Figure 2: Dimension of rooms and view 'A' for H1: (a) & (d); H2: (b) & (e); and H3: (c) & (f).
Figure 3: Section X-X' of measure room in: (a) H1; (b) H2 and (c) H3.
Figure 4: Views of elevations. Boxed locations indicate location of measured rooms in: (a) H1; (b) H2 and (c) H3.

Figure 5: Mean Daylight Ratio at different vertical room locations in H1, H2 and H3.

Figure 6: Mean Daylight Ratio at different room orientation in: (a) H1; (b) H2 and (c) H3.
Figure 7: Mean Luminance of window at different vertical room locations in H1, H2 and H3.

Figure 8: Mean Luminance of window at different room orientation in: (a) H1; (b) H2 and (c) H3.

Figure 9: Enough daylighting in Overcast Day: (a), (c) & (e); Clear day: (b), (d) & (f). Inadequate (-3) to Adequate (3)
Figure 10: Satisfy with daylighting performance in room for: (a) H1; (b) H2 & (c) H3. Dissatisfied (-3) to Satisfied (3).

Figure 11: Window allows adequate daylighting into your room for: (a) H1; (b) H2 & (c) H3. Disagree (-3) to Agree (3).
Tables sent to 'Indoor and Built Environment Journal'

Table 1: Description of questions for visual comfort

<table>
<thead>
<tr>
<th>No.</th>
<th>Question</th>
<th>Scale type</th>
<th>Day condition/time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Describe your visual comfort in this room when only depending on natural lighting during.</td>
<td>('dark' to 'bright')</td>
<td>Overcast day</td>
</tr>
<tr>
<td>2</td>
<td>Describe your visual comfort in this room when only depending on natural lighting during.</td>
<td>('dark' to 'bright')</td>
<td>Clear day</td>
</tr>
<tr>
<td>3</td>
<td>Is natural lighting alone enough to light this room?</td>
<td>('inadequate' to 'adequate')</td>
<td>Overcast day</td>
</tr>
<tr>
<td>4</td>
<td>Is natural lighting alone enough to light this room?</td>
<td>('inadequate' to 'adequate')</td>
<td>Clear day</td>
</tr>
<tr>
<td>5</td>
<td>Are you satisfied with the natural lighting condition of this room?</td>
<td>Overall</td>
<td>None</td>
</tr>
</tbody>
</table>
| 6   | How do you classify the room’s brightness during these hours (regardless of any weather condition): | ('dark' to 'bright') | i) Morning  
|     |                                                                          |             | ii) Afternoon  
|     |                                                                          |             | iii) Evening |
| 7   | Do you agree that the window serves its purpose in allowing natural light into the room? | ('disagree' to 'agree') | None |
| 8   | Do you pull on the window curtains? | ('never' to 'always') | Clear days |
| 9   | Do you experience glare sensation? | ('never' to 'always') | Clear day |
| 10  | Do you switch on the artificial lights during the daytime? | ('never' to 'always') | Clear day |

Table 2: Classification of effect size.

<table>
<thead>
<tr>
<th>Partial eta-squared ($\eta^2_p$)</th>
<th>Site of effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01 ≤ $\eta^2_p$ &lt; 0.06</td>
<td>Small</td>
</tr>
<tr>
<td>0.06 ≤ $\eta^2_p$ &lt; 0.14</td>
<td>Medium</td>
</tr>
<tr>
<td>$\eta^2_p$ ≥ 0.14</td>
<td>Large</td>
</tr>
</tbody>
</table>

Table 3: Summary of external horizontal illumination during measurement period

<table>
<thead>
<tr>
<th>External horizontal illumination, Klx</th>
<th>12-14 May</th>
<th>19-21 May</th>
<th>27-29 May</th>
<th>3-5 June</th>
<th>10-12 June</th>
<th>17-19 June</th>
<th>24-26 June</th>
<th>1-3 July</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>48</td>
<td>52</td>
<td>48</td>
<td>52</td>
<td>51</td>
<td>43</td>
<td>48</td>
<td>54</td>
</tr>
<tr>
<td>Min.</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>10</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Max.</td>
<td>115</td>
<td>115</td>
<td>109</td>
<td>109</td>
<td>108</td>
<td>105</td>
<td>104</td>
<td>103</td>
</tr>
<tr>
<td>S. D (σ)</td>
<td>35</td>
<td>38</td>
<td>34</td>
<td>39</td>
<td>31</td>
<td>25</td>
<td>27</td>
<td>29</td>
</tr>
</tbody>
</table>

Table 4: List of Overcast (OC) and Clear Days (CD) during objective measurement period

<table>
<thead>
<tr>
<th>Case study</th>
<th>OC Dates</th>
<th>CD Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1</td>
<td>13th May</td>
<td>12th May</td>
</tr>
<tr>
<td></td>
<td>19th May</td>
<td>14th May</td>
</tr>
<tr>
<td></td>
<td>20th May</td>
<td>21st May</td>
</tr>
<tr>
<td>H2</td>
<td>28th May</td>
<td>27th May</td>
</tr>
<tr>
<td></td>
<td>3rd June</td>
<td>29th May</td>
</tr>
<tr>
<td></td>
<td>4th June</td>
<td>12th June</td>
</tr>
<tr>
<td></td>
<td>5th June</td>
<td>18th June</td>
</tr>
<tr>
<td></td>
<td>10th June</td>
<td></td>
</tr>
<tr>
<td></td>
<td>11th June</td>
<td></td>
</tr>
<tr>
<td></td>
<td>17th June</td>
<td></td>
</tr>
<tr>
<td></td>
<td>19th June</td>
<td></td>
</tr>
<tr>
<td>H3</td>
<td>25th June</td>
<td>24th June</td>
</tr>
<tr>
<td></td>
<td>26th June</td>
<td>1st July</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2nd July</td>
<td>2nd July</td>
</tr>
<tr>
<td></td>
<td>3rd July</td>
<td></td>
</tr>
</tbody>
</table>

Table 5: ANOVA repeated measures of External illumination during overcast (OD) and clear day (CD) in H1, H2 and H3

<table>
<thead>
<tr>
<th>Day</th>
<th>Mean</th>
<th>S.D</th>
<th>Partial eta Squared</th>
<th>Significant</th>
</tr>
</thead>
<tbody>
<tr>
<td>OD</td>
<td>57</td>
<td>±31</td>
<td>0.14</td>
<td>p &lt; 0.01</td>
</tr>
</tbody>
</table>
Table 6: Internal horizontal illumination level at three room levels on the first, fifth and top floors of H1, H2 and H3.

<table>
<thead>
<tr>
<th>Orientation</th>
<th>H1</th>
<th>H2</th>
<th>H3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1st fl</td>
<td>3rd fl</td>
<td>5th fl</td>
</tr>
<tr>
<td>North Mean Mean</td>
<td>447</td>
<td>497</td>
<td>169</td>
</tr>
<tr>
<td>S.D</td>
<td>±306</td>
<td>±100</td>
<td>±702</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>±876</td>
</tr>
<tr>
<td>South Mean Mean</td>
<td>336</td>
<td>405</td>
<td>137</td>
</tr>
<tr>
<td>S.D</td>
<td>±191</td>
<td>±72</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>±702</td>
</tr>
<tr>
<td>West Mean Mean</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S.D</td>
<td></td>
<td></td>
<td>±664</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>±573</td>
</tr>
<tr>
<td>South-East Mean</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S.D</td>
<td></td>
<td></td>
<td>±644</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>±537</td>
</tr>
<tr>
<td>South-West Mean</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S.D</td>
<td></td>
<td></td>
<td>±573</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>±537</td>
</tr>
<tr>
<td>North-West Mean</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S.D</td>
<td></td>
<td></td>
<td>±664</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>±573</td>
</tr>
<tr>
<td>North-east Mean</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S.D</td>
<td></td>
<td></td>
<td>±664</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>±537</td>
</tr>
</tbody>
</table>

Note: ' - ' = Not available

Table 7: Daylight ratio (%) level at three room levels on the first, fifth and top floors of H1, H2 and H3.

<table>
<thead>
<tr>
<th>Daylight Ratio, %</th>
<th>H1</th>
<th>H2</th>
<th>H3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1st fl</td>
<td>3rd fl</td>
<td>5th fl</td>
</tr>
<tr>
<td>North Mean Mean</td>
<td>1.2</td>
<td>1.3</td>
<td>0.5</td>
</tr>
<tr>
<td>S.D</td>
<td>±0.8</td>
<td>±0.8</td>
<td>±0.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>±1.7</td>
</tr>
<tr>
<td>South Mean Mean</td>
<td>1.0</td>
<td>1.4</td>
<td>0.5</td>
</tr>
<tr>
<td>S.D</td>
<td>±0.6</td>
<td>±1.3</td>
<td>±0.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>±1.7</td>
</tr>
<tr>
<td>West Mean Mean</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S.D</td>
<td></td>
<td></td>
<td>±1.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>±1.3</td>
</tr>
<tr>
<td>South-East Mean</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S.D</td>
<td></td>
<td></td>
<td>±1.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>±1.3</td>
</tr>
<tr>
<td>South-West Mean</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S.D</td>
<td></td>
<td></td>
<td>±1.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>±1.3</td>
</tr>
<tr>
<td>North-West Mean</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S.D</td>
<td></td>
<td></td>
<td>±1.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>±1.3</td>
</tr>
<tr>
<td>North-east Mean</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S.D</td>
<td></td>
<td></td>
<td>±1.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>±1.3</td>
</tr>
</tbody>
</table>

Note: ' - ' = Not available

Table 8: ANOVA repeated measures of daylight ratio during Overcast and Clear Days in H1, H2 and H3.

<table>
<thead>
<tr>
<th>Mean Daylight Ratio (%) for different weather types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case</td>
</tr>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>H1</td>
</tr>
<tr>
<td>H2</td>
</tr>
<tr>
<td>H3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mean Daylight Ratio (%) for different Daytime period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case</td>
</tr>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>H1</td>
</tr>
<tr>
<td>H2</td>
</tr>
<tr>
<td>H3</td>
</tr>
</tbody>
</table>
Table 10: Luminance of window (cd/m²) level at three room levels on the first, fifth and top floors of HI, H2 and H3.

<table>
<thead>
<tr>
<th>Orientation</th>
<th>HI 1st flr</th>
<th>HI 5th flr</th>
<th>HI 9th flr</th>
<th>H2 1st flr</th>
<th>H2 5th flr</th>
<th>H2 10th flr</th>
<th>H3 1st flr</th>
<th>H3 5th flr</th>
<th>H3 10th flr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>1183</td>
<td>1610</td>
<td>3061</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>979</td>
<td>3774</td>
<td>3786</td>
</tr>
<tr>
<td>S.D (±)</td>
<td>686</td>
<td>981</td>
<td>1655</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>510</td>
<td>1439</td>
<td>1318</td>
</tr>
<tr>
<td>Mean</td>
<td>409</td>
<td>1653</td>
<td>2036</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>S.D (±)</td>
<td>209</td>
<td>726</td>
<td>903</td>
<td>-</td>
<td>-</td>
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<td>-</td>
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<tr>
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<td>-</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>593</td>
<td>1151</td>
<td>5113</td>
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<td>S.D (±)</td>
<td>-</td>
<td>-</td>
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<td>250</td>
<td>514</td>
<td>2437</td>
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<tr>
<td>S.D (±)</td>
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<td>-</td>
<td>-</td>
<td>-</td>
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<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>Mean</td>
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<td>3761</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>175</td>
<td>1008</td>
<td>1877</td>
</tr>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1367</td>
<td>3682</td>
<td>3649</td>
</tr>
<tr>
<td>S.D (±)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>846</td>
<td>1613</td>
<td>1579</td>
</tr>
<tr>
<td>Mean</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>913</td>
<td>1210</td>
<td>1388</td>
</tr>
<tr>
<td>S.D (±)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>542</td>
<td>649</td>
<td>646</td>
</tr>
<tr>
<td>Mean</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>853</td>
<td>2279</td>
<td>2643</td>
</tr>
<tr>
<td>S.D (±)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>525</td>
<td>908</td>
<td>1067</td>
</tr>
</tbody>
</table>

Note: '-' = Not available

Table 11: ANOVA repeated measures of luminance of window during Overcast and Clear Days in HI, H2 and H3.

<table>
<thead>
<tr>
<th>Case</th>
<th>Mean Luminance of window (cd/m²) for different weather types</th>
<th>Overcast day</th>
<th>Clear Day</th>
<th>( \eta^2 ) according to Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>HI (n = 100)</td>
<td>1836 (s.d = ±1183)</td>
<td>1482</td>
<td>3761</td>
<td>0.14 (p&lt;0.01)</td>
</tr>
<tr>
<td>H2 (n = 108)</td>
<td>2150 (s.d = ±1620)</td>
<td>2565</td>
<td>3649</td>
<td>0.06 (p&lt;0.01)</td>
</tr>
<tr>
<td>H3 (n = 90)</td>
<td>2728 (s.d = ±2179)</td>
<td>2307</td>
<td>3649</td>
<td>0.09 (p&lt;0.05)</td>
</tr>
<tr>
<td>( \eta^2 ) according to Weather type</td>
<td>0.16 (p&lt;0.01)</td>
<td>0.07 (p&lt;0.05)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 12: ANOVA repeated measures of luminance of window in the morning (8:00 am to 11:59 am), afternoon (12:00 pm to 2:59 pm) and evening (3:00 pm to 5:59 pm) in HI, H2 & H3.

<table>
<thead>
<tr>
<th>Case</th>
<th>Mean Luminance of window (%) for different Daytime period</th>
</tr>
</thead>
<tbody>
<tr>
<td>HI</td>
<td>Morning Afternoon Evening ( \eta^2 ) according to Cases</td>
</tr>
<tr>
<td>HI (n = 100)</td>
<td>1852 (s.d = ±1329) 2263 (s.d = ±1278) 763 (s.d = ±691) 0.31 (p=0.01)</td>
</tr>
<tr>
<td>H2 (n = 108)</td>
<td>2381 (s.d = ±1620) 2564 (s.d = ±1623) 1593 (s.d = ±1266) 0.12 (p=0.01)</td>
</tr>
<tr>
<td>H3 (n = 90)</td>
<td>1470 (s.d = ±1387) 3032 (s.d = ±2179) 2873 (s.d = ±2586) 0.21 (p=0.01)</td>
</tr>
</tbody>
</table>

Table 13: Summary of mean estimation for occupants’ visual comfort during overcast & clear day in HI, H2 & H3 using ANOVA repeated measures. Dark (-3) to Bright (3).

<table>
<thead>
<tr>
<th>Case</th>
<th>Mean visual comfort vote for different Weather Types</th>
<th>Overcast day</th>
<th>Clear day</th>
<th>( \eta^2 ) according to Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>HI (n = 100)</td>
<td>-0.4 (s.d = ±1.4) 1.3 (s.d = ±1.4)</td>
<td>0.43 (p=0.01)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H2 (n = 108)</td>
<td>-0.3 (s.d = ±1.3) 1.4 (s.d = ±1.3)</td>
<td>0.53 (p=0.01)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H3 (n = 90)</td>
<td>-0.4 (s.d = ±1.4) 1.5 (s.d = ±1.3)</td>
<td>0.54 (p=0.01)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 14: Summary of mean estimation for occupants’ visual comfort in the morning, afternoon and evening in HI, H2 & H3. Dark (-3) to Bright (3).

<table>
<thead>
<tr>
<th>Case</th>
<th>Mean visual comfort vote for different Daytime period</th>
<th>Morning</th>
<th>Afternoon</th>
<th>Evening</th>
<th>( \eta^2 ) according to Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>HI (n = 100)</td>
<td>0.4 (s.d = ±1.5) 1.5 (s.d = ±1.4)</td>
<td>0.25 (p=0.01)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H2 (n = 108)</td>
<td>0.7 (s.d = ±1.7) 1.9 (s.d = ±1.2)</td>
<td>0.24 (p=0.01)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H3 (n = 90)</td>
<td>0.9 (s.d = ±1.5) 2.0 (s.d = ±1.1)</td>
<td>0.33 (p=0.01)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 15: Correlation between occupant’s curtain usage with glare during clear day (CD). Never (-3) to Always (3).

<table>
<thead>
<tr>
<th>Case</th>
<th>Mean (s.d)</th>
<th>Pearson Correlation (Sig.: 2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1 (n = 100)</td>
<td>Curtain usage</td>
<td>Glare in CD</td>
</tr>
<tr>
<td></td>
<td>-0.1 (±2.0)</td>
<td>-0.5 (±1.9)</td>
</tr>
<tr>
<td>H2 (n = 108)</td>
<td>Curtain usage</td>
<td>Glare in CD</td>
</tr>
<tr>
<td></td>
<td>1.1 (±1.7)</td>
<td>0.7 (±1.8)</td>
</tr>
<tr>
<td>H3 (n = 90)</td>
<td>Curtain usage</td>
<td>Glare in CD</td>
</tr>
<tr>
<td></td>
<td>1.0 (±1.9)</td>
<td>0.3 (±1.8)</td>
</tr>
</tbody>
</table>

Table 16: Correlation between occupant’s artificial lighting usage with daylight availability during clear day (CD). Never (-3) to Always (3).

<table>
<thead>
<tr>
<th>Case</th>
<th>Mean (s.d)</th>
<th>Pearson Correlation (Sig.: 2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1 (n = 100)</td>
<td>Switch lights</td>
<td>Daylighting in CD</td>
</tr>
<tr>
<td></td>
<td>-1.4 (±1.8)</td>
<td>1.3 (±1.4)</td>
</tr>
<tr>
<td>H2 (n = 108)</td>
<td>Switch lights</td>
<td>Daylighting in CD</td>
</tr>
<tr>
<td></td>
<td>-1.5 (±1.8)</td>
<td>1.4 (±1.3)</td>
</tr>
<tr>
<td>H3 (n = 90)</td>
<td>Switch lights</td>
<td>Daylighting in CD</td>
</tr>
<tr>
<td></td>
<td>-1.2 (±1.9)</td>
<td>1.5 (±1.3)</td>
</tr>
</tbody>
</table>