Energy performance: A comparison of four different multi-residential building designs and forms in the equatorial region

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Energy Performance: A Comparison of Four Different Multi-residential Building Designs and Forms in The Equatorial Region

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Part 1

Introduction

1.1. Introduction
1.2. Objectives of study
1.1. Introduction

- Energy consumption & energy efficiency
  - Commercial & residential sector: 13% of total energy consumption & 48% of electricity consumption on Malaysia (Al-Mofleh et al., 2009).
  - Building sector: major energy consumer with nearly half of the world’s energy used > providing environmental conditioning in buildings & 60-70% of the total energy in non-industrial building is consumed by air-conditioning, lighting & mechanical ventilation (Omer, 2008).
  - Malaysian National Energy Efficiency Master Plan 2010 outlined productive use of energy consumption to promote energy efficiency in built environment.
  - 10th Malaysia Plan: energy saving of 4,000 kilo tones of oil equivalent (ktoe) by 2015 (Economic Planning Unit, 2011).
Green building & passive building design

- *Reduce or eliminate* negative environmental impacts & improve existing non-sustainable design, construction & operation practices (Tiyok, 2009) >>> *efficient use* of natural resources.

- Most important step that can contribute to energy conservation besides building services design & appliances and occupant behavior (Al-Mofleh et al., 2009) >>> difficult to control & maintain.

- Well known strategies: *day lighting & natural ventilation.*
  - Daylighting: reduced 10% and 13% annual electricity consumption (Li et al., 2002; Zain-Ahmed et al., 2002).
  - Combination: reduced 43% of energy reduction (Omer, 2008; Candido et al., 2010).
Energy audit

- Most **important step of energy management activity** and can contribute to energy conservation (Haji-Sapar & Lee, 2005).

- Different levels of sophistication: walkthrough audit & detailed audit (EMSD, 2007)

- ASHRAE (ASHRAE, 2004) - Three different levels of analysis:
  - Preliminary energy use analysis
  - Level I: Walkthrough analysis
  - Level II: Energy survey and analysis
  - Level III: Detailed analysis of capital-intensive modifications
- **Multi-storey residential building**
  - Student hall of residence, key worker accommodation, care homes and sheltered house, containing catering facilities, lounges, dining rooms, health and leisure areas, offices, meeting rooms and other support areas such as laundry facilities (BREEAM, 2010).

- **Millennial generation**
  - Majority of the university students currently.
  - Also acknowledge as New Boomers Generation, who born from 1980 onwards (millennial generation, n.d.).
  - Brought up using digital technologies, electrical gadgets and automobiles >>> considered as the largest consumers of energy as compared to earlier generations, Baby Boomers (who born from 1946 to 1964) and Y (who born from 1965 to 1980) (Meriac et al., 2010).
1.2. Objectives of study

- **Main objective**
  - Analyse the *energy performance* of four low-rise residential colleges, regarding the *implementation of green building strategies* particularly on *daylighting & natural ventilation*.

- **Sub objective**
  - Find out the *electricity consumption patterns* of the *Millennial Generation*
  - Reveal the *effects of recent adoption of green building strategies* in influencing the total energy consumption at residential college.
  - Fill in the *knowledge gap* on passive energy design in residential college buildings.
Part 2 Research Design & Approaches

2.1. Building description
2.2. Building design studies
2.3. Performance of electric use
2.1. Building description

- **K1**: linear arrangement with fixed opening at the end of corridor at each level (705 residents).

The floor plan of K1 – linear arrangement

The fixed opening at the both end of corridor
**K2**: linear arrangement with fixed opening at the end and middle of corridor at each level (1,001 residents).

The floor plan of K2 – linear arrangement

The fixed opening at the both end and middle of corridor
K3: internal courtyard (885 residents).

The floor plan of K3 – internal courtyard

The internal courtyard with open corridor
- **K4**: internal courtyard with balcony at each residential unit (897 residents).
- **Year established:**

- **Residential unit/room:**
  - Generally, limit to two occupants per room.
  - Non air-conditioned and provided at least with one ceiling fan & two fluorescent lamps.

- **Location:** University of Malaya campus (3°7’1”N and 101°39’12”E).

- **Climate:**
  - Consistently hot and humid all the year
  - Annual average temperature between 23 to 32 °C
  - Average precipitation reaching up to 190mm.
  - Affected by the weaker south-east monsoon (April-September).
2.2. Building design studies

- The blue prints – site plan, architectural drawings and structural drawings
- Site visits
- The elements of bioclimatic design (passive mode) introduced by Yeang (Yeang, 2008)
  - Built-form configuration, orientation and site layout planning.
  - Enclosural and façade design
  - Solar-control devices
  - Passive daylight concepts
  - Wind & natural ventilation
  - Landscaping
2.3. Performance of electric use

- Energy Intensity, EI (kWh/m$^2$) :
  \[ EI = \frac{AEC}{TFA} \]
  
  \( AEC \): annual energy consumption (kWh)
  
  \( TFA \): total floor area (m$^2$) (Saidur, 2009)

- Energy use per unit floor area :
  - Normalised Performance Indicators (NPI) (Kamaruzzaman & Edwards, 2006)
  - Building Energy Performance (BEP) (EMSD, 2007)

- Energy Efficiency Index, EEI (kWh/m$^2$/year)
  - Note: residential buildings in Malaysia amount to approximately 10 to 25 kWh/m$^2$ (10-20 times lower compared to office buildings which in recent times, in the range of 200 to 250 kWh/m$^2$) (Ibrahim, 2008; Chou, 2004; Iwaro & Mwasha, 2010; Aun, 2009).
Part 3

Results & Discussion

3.1. Macronutrients element
3.2. Statistical analysis
## 3.1. Characteristic & Green building strategies

<table>
<thead>
<tr>
<th>Internal systems</th>
<th>Characteristic</th>
<th>K1</th>
<th>K2</th>
<th>K3</th>
<th>K4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Built-form configuration, orientation, site layout planning &amp; features</td>
<td>Form of building</td>
<td>Low rise</td>
<td>Low-rise</td>
<td>Low-rise</td>
<td>Low-rise</td>
</tr>
<tr>
<td></td>
<td>Building layout</td>
<td>Linear arrangement</td>
<td>Linear arrangement</td>
<td>Courtyard arrangement</td>
<td>Courtyard arrangement</td>
</tr>
<tr>
<td></td>
<td>Orientation to sun path</td>
<td>N - S, NW - SE &amp; NE - SW</td>
<td>N - S</td>
<td>N - S</td>
<td>N - S &amp; W - E</td>
</tr>
<tr>
<td></td>
<td>Shape of the building's floor plate</td>
<td>Rectangle</td>
<td>Rectangle</td>
<td>L -shape</td>
<td>L -shape</td>
</tr>
<tr>
<td></td>
<td>Wind direction of the locality</td>
<td>SW</td>
<td>SW</td>
<td>SW</td>
<td>SW</td>
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<tr>
<td></td>
<td>Floor level (excluding GF)</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
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<tr>
<td></td>
<td>Total floor area (m²)</td>
<td>11,427.67</td>
<td>22,288.14</td>
<td>18,212.51</td>
<td>34,305.32</td>
</tr>
<tr>
<td>Residential unit-form &amp; configuration</td>
<td>Typical room dimension (l) x (w) x (h)</td>
<td>4.98 x 3.3 x 2.5</td>
<td>4.15 x 3.88 x 2.91</td>
<td>5.0 x 3.4 x 2.77</td>
<td>5.0 x 4.0 x 2.87</td>
</tr>
<tr>
<td></td>
<td>Typical room’s floor area (m²)</td>
<td>16.43</td>
<td>16.10</td>
<td>17.00</td>
<td>20.00</td>
</tr>
<tr>
<td></td>
<td>Typical room volume (m³)</td>
<td>41.09</td>
<td>46.86</td>
<td>47.09</td>
<td>57.40</td>
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<tr>
<td></td>
<td>Typical of corridor width (m)</td>
<td>1.50</td>
<td>1.65</td>
<td>1.87</td>
<td>1.6</td>
</tr>
<tr>
<td>Enclosural &amp; façade design</td>
<td>N - S</td>
<td>N - S, NW - SE &amp; NE - SW</td>
<td>N - S</td>
<td>N - S</td>
<td>N - S &amp; W - E</td>
</tr>
<tr>
<td></td>
<td>Window area (m²)</td>
<td>2.60</td>
<td>0.82</td>
<td>6.46</td>
<td>7.60</td>
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<td></td>
<td>Window to wall ratio</td>
<td>0.32</td>
<td>0.07</td>
<td>0.69</td>
<td>0.76</td>
</tr>
<tr>
<td></td>
<td>Operable window area (m²)</td>
<td>2.60</td>
<td>0.82</td>
<td>4.07</td>
<td>4.18</td>
</tr>
<tr>
<td></td>
<td>Operable window to wall ratio</td>
<td>0.32</td>
<td>0.07</td>
<td>0.43</td>
<td>0.50</td>
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<td></td>
<td>Window design</td>
<td>Louver window/Jalousie</td>
<td>Louver window/Jalousie</td>
<td>Centre pivot &amp; awning</td>
<td>Centre pivot &amp; awning</td>
</tr>
<tr>
<td></td>
<td>Location</td>
<td>N - S, NW - SE &amp; NE - SW</td>
<td>N - S</td>
<td>N - S</td>
<td>N - S &amp; W - E</td>
</tr>
<tr>
<td>Solar control devices</td>
<td>Horizontal overhangs along the wall with windows</td>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td></td>
<td>Vertical overhangs along the wall with windows</td>
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<tr>
<td></td>
<td>Tinted window glass</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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</tr>
<tr>
<td></td>
<td>Balcony/Veranda</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Deep recesses</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td></td>
<td>Internal courtyard</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Passive daylight concepts</td>
<td>Articulated light shelves</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Light pipes</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td></td>
<td>Internal courtyard</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
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<td>Balcony/Veranda</td>
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<td>✓</td>
</tr>
<tr>
<td>Wind &amp; natural ventilation</td>
<td>Window opening with horizontal adjustable/ closing devices</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Window opening with vertical adjustable/closing devices</td>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>High level fixed/adjustable exhaust opening</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Low level fixed/adjustable exhaust opening</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Wing walls above residential unit entrance door &amp; wall</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Wall opening (create wind pressure inside room)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Balconies/Veranda</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Internal courtyard</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Location of opening with respect to wind direction</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Landscaping</td>
<td>Green area (%)</td>
<td>52.25</td>
<td>52.65</td>
<td>60.70</td>
<td>57.97</td>
</tr>
<tr>
<td>Others</td>
<td>Corridor</td>
<td>Adjustable &amp; fixed opening devices at the both end of corridor at each level</td>
<td>Fixed opening at the middle &amp; both end of corridor at each level</td>
<td>Open corridor at each level which facing to internal courtyard</td>
<td>Open corridor at each level which facing to internal courtyard</td>
</tr>
<tr>
<td></td>
<td>Staircase area</td>
<td>Small fixed opening devices</td>
<td>Small adjustable &amp; fixed opening devices</td>
<td>Open staircase area</td>
<td>Open staircase area</td>
</tr>
</tbody>
</table>

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**The 1st CLEAN ENERGY AND TECHNOLOGY (CET 2011)**  
**27th - 29th JUNE 2011, KUALA LUMPUR, MALAYSIA**
The ranking of green building strategies implementation

K3 > K4 > K1 > K2

Note: More wind and natural ventilation design strategies being implemented as compared to passive daylight strategies.
• Orientation
  • North-south for residential unit/room = heavily reduces the thermal gain
  • West-east for services area including toilets & bathroom = lower the humidity levels & eliminating risk of mould growth
The best utilisation of natural ventilation & day lighting

- Courtyard + wing walls = air circulation & day light inside the residential unit/room.
- Open corridor = limit the usage of artificial lighting
- Glare protection & adjustable natural ventilation option
  - Two types of tinted windows: centre pivot & awning = offer the occupant the possibility to channel the outside air/wind, play a role as high level exhaust opening & articulate light shelves.
Largest green area exceeding 60%
Flat roof design offer big potential of a rooftop garden = help to decrease the heat penetration through the roof
- **Orientation & built form**
  - North-south & west-east = reduces the thermal gain at the some part of buildings
  - L-shape of the building’s floor plate = give a shadow effects to adjacent buildings with west-east orientation.
  - Largest floor area (20.0m\(^2\)) & volume (57.4m\(^2\)) > promoting air circulation.
• The best utilisation of natural ventilation & day lighting
  • Wall opening = wind pressure in the cubicle > provides air circulation into residential unit/room.
  • Open corridor + Courtyard = limit the usage of artificial lighting
  • Glare protection & full control of adjustable natural ventilation options
    • Types of tinted windows : casement = offer the occupant the possibility to channel the outside air/wind.
    • Balcony
K1 vs. K2

- **Both**: Less adaptation of natural ventilation & day lighting strategies.
  - Not orientated to sun path (west-east)
  - Solar control devices – horizontal overhangs & awning

- More green building strategies implemented at K1 as compared to K2
K1:

- Solar control devices – vertical overhangs
- Low exhausted opening
- Bigger window to wall ratio
- Wing wall above the entrance door and wall of each residential unit/room > encourage natural ventilation & daylighting
- Larger scale of fixed opening devices at staircase > creates wind pressure effects
- **K2:**
  - Open corridors at each floors in the middle of building > increase the effects of natural ventilation & daylighting
  - Small scale of adjustable opening devices at staircase area
The ranking of green building strategies implementation

K3 > K4 > K1 > K2

Note: More wind and natural ventilation design strategies being implemented as compared to passive daylight strategies
3.2. The performance of electric use (2005-2009)

<table>
<thead>
<tr>
<th>Statistical analysis</th>
<th>K1 TFA : 11,427.67 m²</th>
<th>K2 TFA : 22,288.14 m²</th>
<th>K3 TFA : 18,212.51 m²</th>
<th>K4 TFA : 34,305.32 m²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Monthly</td>
<td>Annual</td>
<td>BEP</td>
<td>EEI</td>
</tr>
<tr>
<td>Mean</td>
<td>61,307</td>
<td>735,679</td>
<td>5.365</td>
<td>64.377</td>
</tr>
<tr>
<td>Median</td>
<td>52,253</td>
<td>617,160</td>
<td>4.572</td>
<td>42.697</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>25,222.16</td>
<td>230,417.20</td>
<td>2.207</td>
<td>20.163</td>
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<tr>
<td>Variance</td>
<td>6.33E+08</td>
<td>5.309E+10</td>
<td>4.871</td>
<td>406.550</td>
</tr>
<tr>
<td>Range</td>
<td>98,898</td>
<td>513,696</td>
<td>8.654</td>
<td>44.952</td>
</tr>
</tbody>
</table>

Note:
- TFA: Total Floor Area (m²)
- BEP: Building Energy Performance (kWh/m²)
- EEI: Energy Efficiency Index (kWh/m²/year)

In the range of average electricity usage value in Malaysia (10 to 25 kWh/m²/year)
The ranking of electricity usage performance

EEI

(kWh/m²/year)

K3 < K4 < K1 < K2

BEP

(kWh/m²)

K4 < K3 < K1 < K2
Part 4

Conclusion
4.0. Conclusion

- Adoption of green building strategies clearly helped to reduce electricity consumption per annum.

- The internal courtyards & balconies should be seriously considered as part of multi storey residential building designs.

- Open corridor at the middle of building layout is identified as an effective approach in optimising daylighting and natural ventilation for energy conservation, particularly building with linear arrangement.

- The average electricity usage by Millennial Generation at non air-conditioned residential college in Kuala Lumpur are in the range 20 to 60 kWh/m²/year.
References

- Economic Planning Unit, Prime Minister’s Department, Tenth Malaysia Plan 2011-2015. Putrajaya: Prime Minister’s Department, 2011.
Acknowledgement

JPPHB, UMCARES and all residential colleges on the University of Malaya campus for their permission of the auditing process including full support in supplying data to be used in this study.
Sekian, terima kasih