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SUB-THEME E : ENERGY EFFICIENCY & RENEWABLE ENERGY

BUILDING ENERGY EFFICIENCY – THE TROPICAL CONTEXT

21st January 2015
Benchmarking Building Energy requires an identification of the parameters relevant to a building. Such parameters can be classed as (1) intrinsic to a building (passive features), (2) function of 'active features' (M&E system) and (3) usage pattern (cultural and usage pattern). While Building Energy for commercial buildings may be well documented, energy index for residential building is less well understood.

This paper considers Building Energy for residential building in the tropical Malaysian context. Energy for cooling of residential building is quickly identified as a major component. The definition of 'thermal comfort' (ASHRAE, Fangers, and Adaptive Thermal Comfort methods) offer fundamentally different approach to design when considering building energy for residential buildings. The impact of thermal massing (particulacrly its impact on 'thermal comfort' rather than traditional 'space-heat-load') is also dealt with topically. Other parameters include electrical appliances (its energy contribution being principally 'socio-economic' and 'life-style-cultural' in nature).

Current benchmarks (kWh/family-year in the Malaysian context) are identified and passive component viz: thermal massing, OTTV and MEPS (minimum energy performance standards) for electrical appliances which impacts residential Building Energy discussed. Future trends for research on the topical issue of ‘thermal-comfort’ in the tropical context for residential buildings are also suggested.
Introduction to Study

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Energy Efficient Residential Building

Ir. H.P. Looi (mektricon@gmail.com)  
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BUILDING SECTOR ENERGY EFFICIENCY PROJECT

Cawangan Alam Sekitar Dan Tenaga (Environment and Energy Division)  
Ibu Pejabat JKR Malaysia (P.W.D. Headquarters Malaysia)  
Tingkat 23, MENARA PJD, No. 50, Jalan Tun Razak, 50400 KUALA LUMPUR  
Telefon: (603) 4041 1924  Faksimili: (603) 4041 1988  
http://www.jkr.gov.my/bseep/
National Energy Balance and Residential Sector

Sales of Electricity (GWh) 2012

- Domestic: 20,301 GWh
- Public Lighting: 1,235 GWh
- Commercial: 33,218 GWh
- Mining: 98 GWh
- Industry: 42,047 GWh
- Export (EGAT): 13 GWh
- Others (Agriculture): 344 GWh
Residential Building Energy Use

Total Energy Use, Urban Family (include Gas Stove)

- Lighting: 7%
- Air Conditioning: 21%
- Ceiling Fan: 4%
- Table Fan: 4%
- PC: 3%
- TV: 5%
- Refrigerator: 3%
- Cooking (Oven): 3%
- Water Heater: 3%
- Washing Machine: 1%
- Gas Stove: 48%

18,500 kWh/year (9,000 kWh due to Gas Stove)
Residential Building Energy Use

Electricity Use Urban Family - 1 AC Unit

- Lighting: 13%
- Air Conditioning: 40%
- Ceiling Fan: 6%
- Table Fan: 6%
- PC: 8%
- TV: 5%
- Refrigerator: 2%
- Cooking (Oven): 7%
- Water Heater: 11%
- Washing Machine: 2%
- Gas Stove: 2%

Total: 9,600 kWh/year
Residential Building Energy Use

Electricity Use Urban Family - No AC Unit

- Lighting: 20%
- Air Conditioning: 15%
- Ceiling Fan: 16%
- Table Fan: 9%
- PC: 12%
- TV: 8%
- Refrigerator: 10%
- Cooking (Oven): 3%
- Water Heater: 7%
- Washing Machine: 6%
- Gas Stove: 0%

6,500 kWh/year
**Conclusion** (typical middle class family):

- Total Energy including Gas for cooking = 18,000 kWh/year (energy equivalent) Gas for cooking constitute 48%.
- Total electrical energy use (2 air cond units = 9,600 kWh/year (electricity, Air cond constitute 40%).
- Total electrical energy use (no air conditioning; passive thermal comfort homes) = 6,500 kWh,
  - Electric fan (for cooling) = 22%
  - Lighting = 20%
  - Electric Oven (cooking) = 16%
Arithmetic mean of electricity use based on sum total of all domestic consumers in Malaysia (kWh per domestic consumer per year). Note the growing trend of Residential Energy Index.
Figure 5 – Mean Electricity Use, Comparative between Singapore & Malaysia Housing sectors
(Source: ‘Suruhanjaya Tenaga’, Malaysia & ‘Energy Market Authority’ of Singapore)
Residential Building Energy Index (Malaysia)

Figure 6 – Mean electricity consumption across socio economics class (kWh/consumer-year) (Appendix A – Estimating Electricity Use Index for Diverse Residential Types)
Figure 7 – Mean electricity consumption across housing types (kWh/consumer-year) (Appendix A – Estimating Electricity Use Index for Diverse Residential Types)
The Residential Building Energy Model

Residential Total Energy Use (2012) = 33,000 GWh

- Electricity 22,000 GWh
- LPG & Kerosene 8,500 GWh

- Occupant Comfort
  - $T_a$ – Temperature
  - $R_a$ – Humidity
  - $W_s$ – Air movement
  - $T_a$ – Toxicity

- Waste
- Solids
- Sewage

- Food Waste, 45%
- Plastic, 24%
- Paper, 7%
- Metal, 6%
- Others, 15%
- Glass, 3%

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## Design Approach in Residential Building Energy

<table>
<thead>
<tr>
<th>Design Approach</th>
<th>Issues Addressed</th>
<th>Technical Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building Thermal Envelope (OTTV and RTTV)</td>
<td>(i) Reducing cooling load for ‘active’ air cond. (static load) (ii) Thermal comfort</td>
<td>(1) ASHRAE fundamentals, chapter 17 and 18. (2) MS1525</td>
</tr>
<tr>
<td>Cooling Load Calculation</td>
<td>(i) Cooling load for ‘active’ air conditioning units (static and dynamic load)</td>
<td>(1) ASHRAE fundamentals, chapter 17 and 18 (2) MS1525 (3) ISO 13786</td>
</tr>
<tr>
<td>Building Thermal Mass</td>
<td>(i) Reducing cooling load for ‘active’ air conditioning (dynamic cooling load) (ii) Thermal comfort</td>
<td>(1) ASHRAE fundamentals, chapter 17 and 18 (2) MS1525 (3) ISO 13786</td>
</tr>
<tr>
<td>Natural Ventilation</td>
<td>(i) ‘Natural’ thermal comfort</td>
<td>(1) ASHRAE 55; (2) ISO 7730 (3) UBBL by-law 39 and 40</td>
</tr>
<tr>
<td>Day Lighting</td>
<td>(i) Day lighting</td>
<td>(1) MS 1525 (2) UBBL by-law 39</td>
</tr>
</tbody>
</table>

**Table 8 – Summary of Passive Design and Technical Standards for Residential Buildings**
The thermal performance of building fabric enclosing internal space (OTTV and RTTV) is mediated by the following parameters:

- The external ambient temperature;
- The orientation of building, particularly glazing towards the direction of the sun;
- The thermal transmittance or conductivity of the building envelope which include enclosing walls, glazing and roof system;
- The radiant emissivity of surfaces of enclosing building envelope.

The concept of building thermal envelope was first adopted by ASHRAE in the 1975 edition of Standard 90.

Figure 12 – The thermal performance of building fabric enclosing internal space.
Deconstructing the OTTV

The OTTV and RTTV have the following generic form:

\[ OTTV_1 = \frac{Q_w + Q_f + Q_{sol}}{A_1} \]

\[ OTTV = \frac{\sum_{i=1}^{n} OTTV_n \times A_n}{\sum_{i=1}^{n} A_n} \]

(1) \( Q_w = \text{Heat conduction through opaque wall (W)} \)
\[ Q_w = A_w \times U_w \times TD_{eq} = (1 - WWR) \times U_w \times TD_{eq} \]

(2) \( Q_f = \text{Heat conduction through windows (W)} \)
\[ Q_f = A_f \times U_f \times \Delta T = WWR \times U_f \times \Delta T \]

(3) \( Q_{sol} = \text{Solar radiation through windows (W)} \)
\[ Q_{sol} = A_f \times SC \times SF = WWR \times SC \times SF \]

(4) \( A_{total} = \text{Gross area of building envelope (m}^2) \)
\[ A_{total} = A_w + A_f \]
## Deconstructing the OTTV

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>OTTV_1</td>
<td>Overall Thermal Transfer Value of individual wall (W/m(^2))</td>
</tr>
<tr>
<td>A_1</td>
<td>area of opaque wall (m(^2))</td>
</tr>
<tr>
<td>U_w</td>
<td>U-value of opaque wall (W/m(^2)°K)</td>
</tr>
<tr>
<td>TD_eq</td>
<td>equivalent temperature difference (°K)</td>
</tr>
<tr>
<td>A_f</td>
<td>area of fenestration (m(^2))</td>
</tr>
<tr>
<td>U_f</td>
<td>U-value of fenestration (W/m(^2)°K)</td>
</tr>
<tr>
<td>ΔT</td>
<td>temperature difference between interior and exterior (°K)</td>
</tr>
<tr>
<td>SC</td>
<td>shading coefficient of fenestration (dimensionless)</td>
</tr>
<tr>
<td>SC_win</td>
<td>shading coefficient of window or sky light glass, this quantity is obtained from manufacturer (dimensionless)</td>
</tr>
<tr>
<td>SSF</td>
<td>solar shade factor of external shading devices (dimensionless)</td>
</tr>
<tr>
<td>SF</td>
<td>solar factor of fenestration (W/m(^2))</td>
</tr>
<tr>
<td>A_total</td>
<td>gross area of building envelope (m(^2));</td>
</tr>
<tr>
<td>WWR</td>
<td>window-to-wall ratio (gross wall area)</td>
</tr>
</tbody>
</table>

### Equations

\[
A_{\text{total}} = A_w + A_f
\]

\[
WWR = \frac{A_f}{A_{\text{total}}}
\]
Deconstructing the OTTV – Basic Heat Transfer

\[ Q_{\text{flow}} = U_w \times A_w \times \Delta T_w \text{ where } (\Delta T_w = T_{so} - T_{si}) \]

- \( Q_{\text{radiant}} \) ~ Solar radiant
- \( Q_{\text{convection}} \) ~ Wind speed

\( T_{outside} = 32^\circ C \)

\( T_{inside} = 24^\circ C \)

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Deconstructing the OTTV – $TD_{eq}$

$$Q_w = \text{Heat conduction through opaque wall} = (1-\text{WWR}) \times U_w \times TD_{eq}$$

$TD_{eq} = \text{Temperature difference equivalent}$

Temperature difference equivalent method is a simplified model approximating the final steady state condition of heat flow:

- Outdoor and indoor ambient temperature ;
- The thermal property of the wall which include:
  1. Thermal resistivity (the converse is thermal conductivity)
  2. Heat capacity and mass (the capacity of the wall to store heat)
- The intensity of solar radiation striking on the surface of exposed wall
- The radiant absorptivity of wall surface (alpha value);
- The emissivity of the wall surface (sigma value)
- Prevailing wind speed /air movement at the surfaces.
Deconstructing the OTTV – $T_{\text{deq}}$ for opaque walls

$$Q_w = \text{Heat conduction through opaque wall} = (1-\text{WWR}) \times U_w \times T_{\text{deq}}$$

Absorption refers to (radian) heat absorption capacity or the ALPHA value.

Mass refers to thermal mass (insulating and heat storage capacity) of wall.

"An OTTV-based energy estimation model for commercial buildings in Thailand" Surapong Chirarattananon et al, 2004
Deconstructing the OTTV – $T_{deq}$ for opaque walls

$$Q_w = \text{Heat conduction through opaque wall} = (1 - \text{WWR}) \times U_w \times T_{deq}$$

<table>
<thead>
<tr>
<th></th>
<th>Malaysia</th>
<th>Singapore</th>
<th>Thailand</th>
<th>Philippines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall $T_{deq}$</td>
<td>15 $\alpha$</td>
<td>ETTV: 12 RETV: 3.4</td>
<td>12 (8 – 27.8)</td>
<td>&lt;125 kg/m³ 15°C &lt;195 kg/m³ 12°C &gt;195 kg/m³ 10°C</td>
</tr>
<tr>
<td>Roof $T_{deq}$</td>
<td>Light: 24 Heavy: 20</td>
<td>12.5</td>
<td>12 (8 – 27.8)</td>
<td>&lt;50 kg/m³: 24°C &lt;230 kg/m³: 20°C &gt;230 kg/m³ 16°C</td>
</tr>
</tbody>
</table>

Notes:
- Light <50 kg/m³
- Heavy <50 kg/m³
- ETTV: envelope thermal envelope.
- RETV: Residential thermal envelope.
- Air cond in residential is mainly switched on at night therefore lower $T_{Deq}$
- Tabulation of $T_{Deq}$ which depends on wall/roof construction
- Alpha values not included.
Deconstructing the OTTV – $\Delta T$ for glazing

\[ Q_f = A_f \times U_f \times \Delta T = WWR \times U_f \times \Delta T \]

$\Delta T = \text{Temperature difference between internal and external space}$

A simplification assumes that:
- $T_{so} \approx T_{outside}$
- $T_{si} \approx T_{inside}$
- $\Delta T \approx T_{outside} - T_{inside}$

Assume thermal mass and absorptivity is negligible.

$T_{outside} = 32^\circ C$

$T_{inside} = 24^\circ C$

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21st January 2015
## Deconstructing the OTTV – ΔT for glazing

\[
Q_f = A_f \times U_f \times \Delta T = WWR \times U_f \times \Delta T
\]

<table>
<thead>
<tr>
<th></th>
<th>Malaysia</th>
<th>Singapore</th>
<th>Thailand</th>
<th>Philippines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall glazing ΔT</td>
<td>6°K</td>
<td>ETTV: 3.4°K</td>
<td>5°K</td>
<td>Office: 3.35°K Hotel: 1.1°K</td>
</tr>
<tr>
<td>Roof skylight ΔT</td>
<td>6°K</td>
<td>4.8°K</td>
<td>??</td>
<td>??</td>
</tr>
</tbody>
</table>

Notes

21st January 2015
Deconstructing the OTTV – Direct sol-rad glazing

\[ Q_{\text{sol}} = \text{Solar radiation through windows (W)} \]

\[ Q_{\text{sol}} = A_f \times SC \times SF = WWR \times SC \times SF \]

\text{SC} = \text{Shielding factor} \quad \text{SF} = \text{Solar factor}

The direct solar radiation entering through glazing:

- Solar radiation which is dependent on time of day, latitude, and seasonal variation.
- The solar shielding on the glazing
- The orientation of building
- The inclination of building

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The OTTV – Direct sol-radiation and glazing

Plot of office solar factor on a plane against inclination at various direction.
The OTTV – Direct sol-radiation and glazing

Plot of office solar factor on a plane against direction at various inclinations.
Thai architect Dr Soontom Boonyatikam

Sunlight is diffused and reflected off the landscape, reducing heat gain into the building.
### The OTTV – Direct sol-radiation and glazing

\[
Q_{sol} = \text{Solar radiation through windows (W)}
\]

\[
Q_{sol} = A_f \times SC \times SF = WWR \times \boxed{SC} \times \boxed{SF}
\]

<table>
<thead>
<tr>
<th></th>
<th>Malaysia</th>
<th>Singapore</th>
<th>Thailand</th>
<th>Philippines</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average Sol Factor</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>wall glazing ((SF_{AV}))</td>
<td>194</td>
<td>ETTV: 211</td>
<td>160</td>
<td>Office: 161</td>
</tr>
<tr>
<td>(SF = F_{AV} \times OF)</td>
<td></td>
<td>RETV: 58.6</td>
<td></td>
<td>Hotels: 142</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Stores: 151</td>
</tr>
<tr>
<td><strong>OF (Orientation Factor)</strong></td>
<td>0.9 – 1.23</td>
<td>ETTV: 0.69– 1.56</td>
<td>tabulation</td>
<td>tabulation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RETV: 0.83– 1.55</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Inclination of wall</strong></td>
<td>Not considered</td>
<td>Yes in OF</td>
<td>Yes in OF</td>
<td>Yes in OF</td>
</tr>
<tr>
<td><strong>Average Sol Factor</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>skylight ((SF_{AV}))</td>
<td>323</td>
<td>485</td>
<td>370</td>
<td>??</td>
</tr>
<tr>
<td>(SF = F_{AV} \times OF)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Inclination of wall:**
- Not considered for Malaysia.

**Average Sol Factor:**
- Malaysia: 194
- Singapore: ETTV: 211, RETV: 58.6
- Thailand: 160
- Philippines: Office: 161, Hotels: 142, Stores: 151
Deconstructing the OTTV – $\Delta T$ for glazing

OTTV and RTTV provide an index of TOTAL external energy infiltration into internal building space via the building envelope.
Deconstructing the OTTV – ΔT for glazing
Deconstructing the OTTV – $\Delta T$ for glazing

The OTTV and RTTV provide a measure of thermal intensity (W/m$^2$) on the building envelope ‘exposed’ to the external environment. The following should be noted:

(a) The OTTV/RTTV method has as its original aim the reduction of (active) cooling load. Notwithstanding, caveats listed below it is a useful tool in the design of passive features of the building envelope.

(b) An estimate of total cooling load due to external heat transfer into internal building space can be estimated based on the thermal transfer values and area of exposed building envelope. However where the percentage of air conditioned space is low, the accuracy of cooling load will not be accurate.

(c) The OTTV method do not take into account other source of heat loads such as air infiltration and latent and other heat sources from occupants and electric appliances inside building.
The ‘building thermal envelope’ approach formulated principally as a tool for estimating cooling load into buildings may be at a disadvantage in the case of residential buildings; where cooling loads are characterised by the following:

(b) **Small heat gain.** Heat gains in residential buildings are principally due to the thermal performance of building envelopes and ventilation or air infiltration for the space air conditioned. Heat gain from electrical appliances and occupants are usually small (compared to commercial buildings).

(c) **Diverse Space Usage.** Space usage is highly diverse and flexible. This also means that load usage profile is highly variable.

(d) **Fewer Zones.** Generally fewer zones are air conditioned (if at all). In typical Malaysian homes only one or two rooms may be air conditioned. The thermal envelope concept for heat load in residential buildings may not be accurate.
Passive Design and Thermal Comfort

Thermal comfort (ASHRAE 55\textsuperscript{[1]} and ISO 7730\textsuperscript{[2]}) is defined as the conditions of environment which can be expressed as thermal comfort.

Six Factors in Fanger’s thermal comfort model:

✓ Metabolic rate (activity level)
✓ Resident clothing insulation
✓ Internal air temperature
✓ Mean radian temperature
✓ Air speed

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\textsuperscript{[1]} ASHRAE 55 – Thermal environmental conditions for human occupancy
\textsuperscript{[2]} ISO 7730 – Moderate thermal environments – Determination of the PMV and PPD indices and specification of the conditions for thermal comfort.
Thermal comfort (ASHRAE 55\textsuperscript{[1]} and ISO 7730\textsuperscript{[2]}) is defined as the conditions of environment which can be expressed as thermal comfort.

\textsuperscript{[1]} ASHRAE 55 – Thermal environmental conditions for human occupancy

\textsuperscript{[2]} ISO 7730 – Moderate thermal environments – Determination of the PMV and PPD indices and specification of the conditions for thermal comfort.
## Passive Design and Thermal Comfort

### Factors affecting thermal comfort

<table>
<thead>
<tr>
<th>Factor</th>
<th>Unit</th>
<th>Secondary factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Metabolic rate of occupant</td>
<td>W/m²</td>
<td>✓ Activity of occupant.</td>
</tr>
<tr>
<td>(1) Clothing Insulation</td>
<td>m²°C/W</td>
<td>✓ Skin temperature of occupant.</td>
</tr>
<tr>
<td>(1) Air temperature (internal)</td>
<td>°C</td>
<td>✓ outside temperature,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>✓ solar insolation,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>✓ thermal performance of building envelope,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>✓ Air infiltration.</td>
</tr>
<tr>
<td>(1) Mean radiate temperature</td>
<td>°C</td>
<td>✓ outside temperature,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>✓ solar insolation,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>✓ radiant emissivity of walls, ceiling, glazing,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>✓ Thermal capacity of building mass at vicinity.</td>
</tr>
<tr>
<td>(1) Air speed (internal)</td>
<td>m/s</td>
<td>✓ Air infiltration, natural ventilation,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>✓ Presence of fan(s)</td>
</tr>
<tr>
<td>(1) Relative humidity</td>
<td>%</td>
<td>✓ Air infiltration, natural ventilation.</td>
</tr>
</tbody>
</table>

The thermal comfort model and six factors affecting thermal comfort
The PMV is given by the equation:

\[ PMV = \left( 0.303 \times e^{-0.038 \cdot M} + 0.028 \right) \times 10^{-3} \times \left[ 5733 - 6.99(M - W) - P_a \right] - 0.42 \times \left[ (M - W) - 58.15 \right] - 1.7 \times 10^{-5}M(5867 - P_a) - 0.0014M(34 - t_a) - 3.96 \times 10^{-8}f_{cl} \times \left[ (t_{cl} + 273)^4 - (t_r + 273)^4 \right] - f_{cl}h_c(t_{cl} - t_a) \]
## Fanger’s Thermal Comfort – Calculation Tool

<p>| | | | | | | | |</p>
<table>
<thead>
<tr>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1</strong> Clothing Insulation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Select maximum clothing insulation (select clothing ensemble to find out its clo insulation value)</td>
<td></td>
<td>Underwear, shirt, trousers, socks, shoes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>This is the insulation value associated with the ensemble;</td>
<td></td>
<td>0.110 m²·°C/W</td>
<td></td>
<td>0.70 clo</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Select the max clothing insulation to use in PMV calculation</td>
<td></td>
<td>0.093 m²·°C/W</td>
<td></td>
<td>0.60 clo</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>2</strong> Activity (metabolic rate)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Select activities to find out metabolic rates</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>This is the insulation value associated with this activity</td>
<td></td>
<td>70.00 W/m²</td>
<td></td>
<td>1.20 met</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Select the max activity level to be used in PMV calculation</td>
<td></td>
<td>69.78 W/m²</td>
<td></td>
<td>1.20 met</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>3</strong> Temperatures</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(a) Input the air temperature of internal space</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(b) Input the mean radiant temperature of internal space</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>27°C</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td><strong>4</strong> Internal environmental conditions</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>(a) Input relative humidity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>(b) Input the air velocity</td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>60.00%</td>
<td></td>
<td>2,139.1 kPa</td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.6 m/s</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>5</strong> Predicted Mean Vote (for thermal comfort)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>0.5</td>
<td></td>
<td></td>
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</tr>
<tr>
<td><strong>6</strong> Predicted percentage dissatisfaction (PPD)</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>10.5%</td>
<td></td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>
Fanger’s Thermal Comfort – Calculation Tool
Fanger’s Thermal Comfort

Air Speed: 0m/s
- Lower Limit (cool)
- Neutral
- Upper Limit (warm)

Air Speed: 0.5m/s
- Lower Limit (cool)
- Neutral
- Upper Limit (warm)

Air Speed: 1.0m/s
- Lower Limit (cool)
- Neutral
- Upper Limit (warm)

Predicted Mean Vote (PMV) for Thermal Comfort based on ASHRAE 55 and ISO 7730
Fanger’s Thermal Comfort

The Concepts of Enclosure Performance on Mean Radiant Temperature, Thermal Discomfort and Requirements for Adaptive/Mechanical Solutions

Building thermal characterization noted as:
- Terrific, Transitional, Traditional, and Terrible
- Based on floor surface flux
- Darker gray shaded areas indicate possible applications for low temperature heating and high temperature cooling.

Upper comfort limit

Lower comfort limit

Floor surface flux based on enclosure performance in moderate to extreme climates noted as:
- High, good, moderate and poor. Shown in IP units, Btu/hr/sf.
- Loads <10 Btu/hr/sf in dark gray shaded areas can operate with fluid temperatures of <90°F for heating and >60°F for cooling using large conductive surface to room heat exchangers for maximum combustion or compression efficiency.
Fanger’s Thermal Comfort

MRT in theory = homogenous
An excel-based software tool to calculate mean radiant temperature in room given weather conditions and thermal characteristics of wall is under development.

**European Standard**

**EN ISO 13786**

December 2007

ICS 91.060.01; 91.120.10

English Version

Thermal performance of building components - Dynamic thermal characteristics - Calculation methods (ISO 13786:2007)

Performance thermique des composants de bâtiment - Caractéristiques thermiques dynamiques - Méthodes de calcul (ISO 13786:2007)


This European Standard was approved by CEN on 7 December 2007.
Building Thermal Mass

- The capacity of building material to store thermal energy and release it at a later period.
- In the tropical context, building mass exposed to solar radiant heat will conduct and store thermal heat within its mass and release it during the cool evening night period.
- A large thermal mass which is kept cool AND insulated or shielded or isolated from solar radiant heat acts as a thermal sink reducing the need for active cooling and improving thermal comfort.
The capacity of building material to store thermal energy and release it at a later period.

In the tropical context, building mass exposed to solar radiant heat will conduct and store thermal heat within its mass and release it during the cool evening night period.

A large thermal mass which is kept cool AND insulated or shielded or isolated from solar radiant heat acts as a thermal sink reducing the need for active cooling and improving thermal comfort.
Thermal properties of building material

- Conductivity (W/mK)
- Density (kg/m³)
- Specific heat (J/kgK)
- Surface emissivity (-)
- Surface shortwave absorptivity (-)
- Vapour resistivity and resistance (MNs/gm or MNs/g).
Types of Thermal Material

✔ Traditional building material with thermal mass include water, rock, earth, brick, concrete, fibrous cement, ceramic tiles etc.

✔ Phase change materials store energy while maintaining constant temperatures, using chemical bonds to store & release latent heat. PCM’s can store five to fourteen times more heat per unit volume than traditional materials. (source: US Department of Energy).

✔ PCM’s include solid-liquid Glauber’s salt, paraffin wax, and the newer solid-solid linear crystalline alkyl hydrocarbons (K-18: 77°F phase transformation temperature).
The basic properties that indicate the thermal behavior of materials are: density ($p$), specific heat ($c_m$), and conductivity ($k$).

The specific heat for most masonry materials is similar (about 0.2-0.25Wh/kg°C).

Therefore, the total heat storage capacity is a function of the total mass of masonry materials, regardless of its type (concrete, brick, stone, and earth).

<table>
<thead>
<tr>
<th>Material</th>
<th>Density (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>600-2200</td>
</tr>
<tr>
<td>Stone</td>
<td>1900-2500</td>
</tr>
<tr>
<td>Bricks</td>
<td>1500-1900</td>
</tr>
<tr>
<td>Earth</td>
<td>1000-1500 (uncompressed)</td>
</tr>
<tr>
<td>Earth</td>
<td>1700-2200 (compressed)</td>
</tr>
</tbody>
</table>
An important property of thermal mass is the **Thermal Time Constant** of a building envelope.

**TTC** = heat capacity \( (Q) \) x resistance \( (R) \) to heat transmission.

The TTC is representative of the effective thermal capacity of a building.

**TTC/area** = heat capacity/unit area \( (Q_A) \) x resistance to heat flow/area

\[ Q_A = \text{thickness} \times \text{density} \times \text{specific heat} \]

**Resistance** = thickness/conductivity (or the U value).

\( \text{TTC}_A \) / area of a composite wall, the \( Q_A R \) value of each layer, including the outside and inside air layers, is calculated in sequence. The \( Q_A R \) for each layer is calculated from the external wall to the center of the section in question:

\[ Q_{Ai} R_i = (c_m \times l \times p)_i \times (R_0 + R_1 + \ldots + 0.5R_i) \]

For a composite surface of n layers, \( \text{TTC}_A = Q_{A1} R_1 + Q_{A2} R_2 + \ldots + Q_{An} R_n \).

The TTCs for each surface is the product of the \( \text{TTC}_A \) multiplied by the area. Glazed areas are assumed to have a TTC of 0. The total TTC\(_{\text{total}}\) of the building envelope equals the sum of all TTCs divided by the total envelope area, including the glazing areas.

**A high TTC indicates a high thermal inertia of the building and results in a strong suppression of the interior temperature swing.**
Diurnal Heat Capacity

DHC is a measure of the building’s capacity to absorb solar energy entering the interior space, and to release the heat to the interior during the night hours. The DHC is of particular importance for buildings in tropical zones.

The DHC of a material is a function of building material’s density, specific heat, conductivity, and thickness. The total DHC of a building is calculated by summing the DHC values of each surface exposed to the interior air.

The DHC for a material increases initially with thickness, then falls off at around 5”. This behavior reflects the fact that after a certain thickness, some of the heat transferred to the surface will be contained in the mass rather than returned to the room during a 24 hour period.
TTC and DHC

Relative values of TTC indicate the thermal capacity of the building when a building is affected mostly by heat flow across the opaque parts of the envelope (i.e., when it is unventilated, and when solar gain is small relative to the total heat transfer through the building envelope).

Relative values of DHC, on the other hand, indicate the thermal capacity for buildings where solar gain is considerable. The DHC also is a measure of how much “coolth” the building can store during the night in a night ventilated building.

Both measures indicate the amount of interior temperature swing that can be expected based on outdoor temperatures (higher values indicate less swing).

\[
\Delta T(\text{swing}) = 0.61Q_s/DHC_{\text{total}},
\]

Qs is the daily total solar energy absorbed in the zone.
Calculation of thermal admittance (Y) & time lag

Software calculation tools under development

Heat transfer matrix:

\[ Z_{ee} = Z_{s2} Z Z_{s1} \]

Where \( Z_{s1} \) and \( Z_{s2} \) are the heat transfer matrices of the boundary layers

Dynamic thermal admittance & time shift of admittance

\[ Y_{11} = -\frac{Z_{11}}{Z_{12}} \quad \text{and} \quad Y_{22} = -\frac{Z_{22}}{Z_{12}} \]

\[ \Delta t = \frac{T}{2\pi} \arg(Y_{nn}) \]
Building which is externally insulated with internal exposed mass.
Here, both TTC and DHC are high. When the building is ventilated at night and closed during the day, it can absorb the heat in the mass with relatively small indoor temperature rise. Best for hot-dry regions.

Building with mass insulated internally.
Here, both the TTC is and DHC are low. The mass will store energy and release energy mostly to the exterior, and the thermal response is similar to a low mass building.

Building with high mass insulated externally and internally.
Here, the building has a high TTC, but a negligible DHC, as the interior insulation separates the mass from the interior. When the building is closed and the solar gain is minimized, the mass will dampen the temperature swing, but if the building is ventilated, the effect of the mass will be negated. With solar gain, the inside temperature will rise quickly, as the insulation prevents absorption of the energy by the mass.

Building with core insulation inside two layers of mass.
Here the TTC is a function of mostly the interior mass and the amount of insulation, and the DHC is a function on the interior mass. The external mass influences heat loss and gain by affecting the delta T across the insulation.
Natural Ventilation

MS 1525:2007 - Section 8.1.4 Ventilation

Outdoor Air-Ventilation Rates should comply with Third Schedule (By Law 41) Article 12 (1) of Uniform Building By Laws, 1984 (UBBL)

12. Fresh air changes.

(1) The minimum scale of fresh air ventilation in conjunction with recycled, filtered and conditioned air system with the requirements of ASHRAE STANDARD 62.73 shall be as follows:

<table>
<thead>
<tr>
<th>Building Type</th>
<th>Minimum Air Changes per Occupant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential building</td>
<td>0.14 cmm per occupant</td>
</tr>
<tr>
<td>Commercial premises</td>
<td>0.14 cmm per occupant</td>
</tr>
<tr>
<td>Factory and Workshop</td>
<td>0.14 cmm per occupant</td>
</tr>
<tr>
<td>School classroom</td>
<td>0.14 cmm per occupant</td>
</tr>
<tr>
<td>Projection room</td>
<td>0.14 cmm per occupant</td>
</tr>
<tr>
<td>Theatre and Auditorium</td>
<td>0.14 cmm per seat</td>
</tr>
<tr>
<td>Cafeteria</td>
<td>0.28 cmm per occupant</td>
</tr>
<tr>
<td>Building of Public Resort</td>
<td>0.28 cmm per occupant</td>
</tr>
<tr>
<td>Office</td>
<td>0.14 cmm per occupant</td>
</tr>
<tr>
<td>Conference Room</td>
<td>0.28 cmm per occupant</td>
</tr>
<tr>
<td>Hospital wards</td>
<td>0.14 cmm per occupant</td>
</tr>
<tr>
<td>Computer Room</td>
<td>0.14 cmm per occupant</td>
</tr>
<tr>
<td>Hotel rooms</td>
<td>0.14 cmm per occupant</td>
</tr>
</tbody>
</table>

For detention and healthcare facilities, the ventilation shall be in conjunction with the mechanical ventilation systems and shall be as follows:

<table>
<thead>
<tr>
<th>Building Type</th>
<th>Minimum Air Changes per Hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basement and garages</td>
<td>Minimum of 6 air changes per hour</td>
</tr>
<tr>
<td>Commercial premises (including laundry and boiler houses)</td>
<td>0.28 cmm per occupant</td>
</tr>
<tr>
<td>Factory and Workshop (the design shall be based on the actual requirements)</td>
<td>0.56 cmm per occupant</td>
</tr>
<tr>
<td>Project room</td>
<td>10 air changes per hour</td>
</tr>
<tr>
<td>Theatre and Auditorium</td>
<td>0.28 cmm per occupant</td>
</tr>
<tr>
<td>Kitchen</td>
<td>20 air changes per hour</td>
</tr>
</tbody>
</table>

Note: All other areas shall meet the minimum requirements of the ASHRAE STANDARD 62.73.
### Natural Ventilation

<table>
<thead>
<tr>
<th>BUILDING TYPE</th>
<th>MINIMUM FRESH AIR VENTILATION  cubic meter/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>RESIDENTIAL</td>
<td>0.14/occupant (0.23 lit/sec/m² floor area average)</td>
</tr>
<tr>
<td>COMMERCIAL OFFICES</td>
<td></td>
</tr>
<tr>
<td>SCHOOL CLASSROOM</td>
<td></td>
</tr>
<tr>
<td>HOSPITAL WARDS</td>
<td></td>
</tr>
<tr>
<td>CONFERENCE ROOMS</td>
<td>0.28/occupant</td>
</tr>
<tr>
<td>FACTORIES</td>
<td>0.21/occupant</td>
</tr>
<tr>
<td>Basement car Park (Mech)</td>
<td>6 air change/hour</td>
</tr>
</tbody>
</table>
Thermal Comfort;

ASHRAE DEFINITION 3 basic conditions in Passive Design for thermal comfort:
- Operative temperature
- Air movement / Wind Speed
- Relative Humidity

Fanger’s PMV-PPD Thermal Comfort Model (for conditioned space).

Adaptive Thermal Comfort Model (for Natural and Hybrid Ventilation Space).
Natural Comfort and Thermal Comfort

Chart 1.2 | Adaptive Thermal Comfort

- 90% Upper Limit
- Toc
- 90% Lower Limit

Operative Temperature (°C) vs. Average Air Temperature (°C)

90% Thermal Acceptability

mektricon@gmail.com
Natural Comfort and Thermal Comfort

- Natural means to maintain air quality
- Vents build-up of toxic gases and indoor pollutants (principally pathogens)

- Low cost/ natural means of maintaining indoor thermal comfort.
FIGURE 9.1  CROSS-SECTION OF AN ATRIUM SPACE WITH NATURAL VENTILATION
mektricon@gmail.com
Natural Comfort and Thermal Comfort

Global Stack Ventilation

Global Cross Ventilation
Natural Comfort and Thermal Comfort

- Wind-driven Cross Ventilation
- Buoyancy-driven Stack Ventilation
- Single-sided Ventilation
Ventilation Design Methodology

Cross Ventilation

Sizing Openings for Cross-Ventilation
Ventilation Design Methodology

STACK VENTILATION

Building Heat Gain Rate (Stack Cooling Capacity)

heat removed: Btu/hr, ft² (W/m²)
air flow rate: cfm/ft² (l/s, m²)

Sizing Stack-Ventilation

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21st January 2015
Passive Design - Conclusion

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21st January 2015
OTTV/RTTV: building envelope is not a good indicator of energy Passive House. It is not even a good indication of air conditioning load in residential building.

The Malaysia OTTV: uses worst case solar insolation and weather data. Other methodology in OTTV development uses “averaged” solar and weather data to

Passive Low Energy Design can be approached from 2 perspectives:
1. Reduction of active cooling load by good thermal envelope (this approach is not satisfactory
2. Thermal Comfort

Passive design for thermal comfort requires consideration of:
1. Thermal envelope with consideration of thermal mass (TTC & DHC);
2. Mean internal radiant temperature which is dependent on TTC & DHC;
3. Natural ventilation and the building form.
PASSIVE DESIGN INDEX

ADAPTABILITY INDEX - 111 1F Bed Room 1

Outside Air Temperature >>

Zone Temperature >>

Index: 1.13

1st January - 31st December

MEKTRICON
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21st January 2015
Passive Design – Area of Research?
Research – Thermal Ponds & the Cool Night Sky

Degrees Celsius

Average  Minimum  Maximum

12:00:00 AM  3:00:00 AM  6:00:00 AM  9:00:00 AM  12:00:00 PM  3:00:00 PM  6:00:00 PM  9:00:00 PM  12:00:00 AM
The Day – Night Sky Conundrum.
Cool Night Sky Conundrum

Day – Solar radiant heat entering from the sky. Ceiling insulation will prevent heat from entering internal space.
During the night the cool night sky acts as a heat sink. The ceiling insulation however will prevent heat from radiating out.
Possible area of research on E.E. in residential buildings

✓ Retractable roof insulation to allow radiation of heat into the cool night sky.
✓ Optimising thermal massing for thermal comfort (TTI, DHC).
✓ Optimising passive design for a naturally cooled house.
✓ The use of ground as a heat sink. Channel air pre cooled in underground chamber before directing into internal space. Current research shows 1m depth ground temp is 26.9°C for the whole year round.
✓ The cool roof riddle.
The dynamics of cooling/heating within roof space is governed by the three issues:

✓ Radiation
✓ Convection
✓ Radiation
74 Software for Passive Design
20th – 21st January 2015, University Putra Malaysia

Sub-theme E: Energy Efficiency & Renewable Energy

Building Energy Efficiency – The Tropical Context

21st January 2015

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Immediate Past President,
Malaysia Green Building Confederation

Thank You for Your Attention!