Passive cooling techniques
theory and practice

Thoughtful Cooling
TOT Workshop on Cooling Interiors Efficiently and Sustainably

Rachana Sansad, Mumbai | 9th January, 2015

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⊙Delhi ⊙Mumbai ⊙Pune ⊙Bangalore ⊙Chennai ⊙New York
Energy efficient buildings are designed in response to sun and climate
Buildings are designed to keep occupant comfortable

Definition of thermal comfort parameters has an impact on energy efficiency
India has a predominantly warm climate

- Hot dry $\Rightarrow$ cooling
- Hot humid $\Rightarrow$ cooling
- Composite $\Rightarrow$ cooling + heating
- Temperate $\Rightarrow$ cooling
- Cold $\Rightarrow$ heating
Energy end-use in buildings in India

Commercial buildings

Residential buildings

There is an estimated 30-50% energy savings potential in these buildings
Passive design might not help solve 100% of the problem, but it certainly will reduce the demand for energy consumption.
Key objectives in passive cooling

① Reduce demand for cooling
  • Avoid overheating

② Reduce the energy required for cooling
  • Integrate passive cooling techniques
Room A vs Room B

- All Brick walls
- You need a 1 ton AC to cool the room
- COOLING LOAD = \( x \)

- All Glass
- You need a 3 ton AC to cool the room
- COOLING LOAD = \( 3x \)
Room A vs Room B

- Mr. A is using the AC for 5 hours a day
- Energy consumption = \( y \)

- Mr. B never shows up for work
- Energy consumption = 0
LOADS vs ENERGY

- **Static**
  - As a result of DESIGN
  - Loads for identical buildings in the same location will be the same
  - Thus, it all depends on the DESIGN!
  - Units: kW/sqm or sqft

- **Dynamic**
  - As a result of USE
  - Energy consumption for identical buildings in the same location can be different.
  - Thus, it all depends on the USER!
  - Units: kWh/sqm or sqft
Key objectives in passive cooling

① Reduce demand for cooling
  • Avoid overheating

② Reduce the energy required for cooling
  • Integrate passive cooling techniques
Techniques to avoid overheating

Objectives:

1. Resist heat gain
2. Promote heat loss
Building bioclimatic chart

Integrates architectural strategies with human comfort needs

![Building Bioclimatic Chart](chart.png)
Building bioclimatic chart

15.7% comfortable hours

Comfort Zones show:
Summer clothing on right,
Winter clothing on left.
Building bioclimatic chart

15.7% comfortable hours

Add passive strategies
shading
High thermal mass
Direct evaporative cooling
Natural ventilation
Internal heat gain

54.3% comfortable hours
Techniques to avoid overheating

① Reduce heat gain
  ① Using thermal mass construction
② Reduce exposed surface
③ Adding insulation
Techniques to avoid overheating

① Reduce heat gain
② Form and orientation
③ Reduce WWR
④ Use shading devices
⑤ Reduce heat gain through glazed areas
⑥ Minimize heat gain around the building
All these strategies do not cool, they reduce overheating.. they reduce cooling demand..
Passive cooling systems

These transfer heat from the building to natural energy sinks, such as the air, water, earth or outer space. Implementation of these systems in buildings reduces energy needed for cooling.
Bihar Museum, Patna
Bihar Museum, Patna

11.6% Comfortable Hours using Selected Strategy (1017 out of 8760 hrs)

Comfort Zones show:
- Summer clothing
- Winter clothing

湿球温度图

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**Bihar Museum, Patna**

**DESIGN STRATEGIES: JANUARY through DECEMBER**

- **11.6%** 1 Comfort (1017 hrs)
- **25.1%** 2 Sun Shading of Windows (2195 hrs)
- **5.0%** 3 High Thermal Mass (442 hrs)
  - 4 High Thermal Mass Night Flushed (0 hrs)
  - 5 Direct Evaporative Cooling (0 hrs)
  - 6 Two-Stage Evaporative Cooling (0 hrs)
- **3.4%** 7 Natural Ventilation Cooling (299 hrs)
- **16.4%** 8 Fan-Forced Ventilation Cooling (0 hrs)
- **10.4%** 9 Internal Heat Gain (1410 hrs)
- **4.8%** 10 Passive Solar Direct Gain Low Mass (0 hrs)
- **11.2%** 11 Passive Solar Direct Gain High Mass (418 hrs)
- **12** Wind Protection of Outdoor Spaces (0 hrs)
- **13** Humidification Only (0 hrs)
- **14** Dehumidification Only (0 hrs)
- **15** Cooling, add Dehumidification if needed (0 hrs)
- **16** Heating, add Humidification if needed (0 hrs)

**Comfort Zones show:**
- Summer clothing
- Wind

**Passive cooling techniques**
Bihar Museum, Patna

DESIGN STRATEGIES: JANUARY through DECEMBER

11.6%  1 Comfort (1017 hrs)
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  14%  14 Dehumidification Only (0 hrs)
  15%  15 Cooling, add Dehumidification if needed (0 hrs)
  16%  16 Heating, add Humidification if needed (0 hrs)

43.7% Comfortable Hours using Selected Strategies
  (3832 out of 8760 hrs)

Comfort Zones show:
  Summer clothing
  Winter
Bihar Museum, Patna

Thus various design strategies will have to be combined within the premise of both comfort models to achieve thermal comfort with reduced systems loads in the building throughout the year.

ASHRAE Std 55 Comfort Model
For conditioned areas

Adaptive Comfort Model
For naturally ventilated areas
Passive cooling systems

These transfer heat from the building to natural energy sinks, such as the air, water, earth or outer space. Implementation of these systems in buildings reduces energy needed for cooling.
Nocturnal ventilative cooling

Concept

- Night time cooling of the thermal mass that gets heated up in the day time
- Heat absorption of the thermal is more efficient during the day
Stack ventilation

CONCEPT
- Works on the principle of thermal buoyancy
- Hot air rises through the stack drawing the cool air inducing the air movement

-Natural ventilation strategy
Solar chimney

CONCEPT
Glazed or black colored surface on the stack increases solar heat gain and accelerates rise in temperature in the stack.
Earth tubes

CONCEPT:

- Ground temperatures at about 3 to 4m do not vary through the year
- Earth is a very large heat sink and can be used to exchange heat
Earth tubes
French School, Damascus, Syria

**Climate responsive design**
- daylight
- night cooling of thermal mass
- natural ventilation
- wind and solar supported chimney
- ground heat exchanger
French School, Damascus, Syria
French School, Damascus, Syria
French School, Damascus, Syria
French School, Damascus, Syria
French School, Damascus, Syria
French School, Damascus, Syria

Typical Class Room - room temperature statistics during time of occupation

- **ambient temperature**
- **operative room temperature lower floor**
- **operative room temperature upper floor**

<table>
<thead>
<tr>
<th>Temperature Range</th>
<th>Number of Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>T &gt; 28 °C</td>
<td>403</td>
</tr>
<tr>
<td>T &gt; 29 °C</td>
<td>350</td>
</tr>
<tr>
<td>T &gt; 30 °C</td>
<td>288</td>
</tr>
<tr>
<td>T &gt; 31 °C</td>
<td>222</td>
</tr>
<tr>
<td>T &gt; 32 °C</td>
<td>177</td>
</tr>
<tr>
<td>T &gt; 33 °C</td>
<td>117</td>
</tr>
<tr>
<td>T &gt; 34 °C</td>
<td>64</td>
</tr>
<tr>
<td>T &gt; 35 °C</td>
<td>31</td>
</tr>
</tbody>
</table>

Passive cooling techniques
Miramar college police station, san diego, California

Thermal chimney performance goals
① Integrate with a whole building natural ventilation system (exterior windows, interior openings – doors, grills, interior windows)
② Meet minimum OA requirements during operation
③ Maintain comfort when outdoor air conditions permit
④ Don’t exceed 160 fpm through openings
⑤ Provide mixed mode HVAC operation
Ventilation Zoning

- Mixed mode ventilation – Thermal Chimney System
- Mixed mode ventilation - Isolated
- Mechanical ventilation only

Thermal Chimney
Typical Airflow Paths – Based on Airflow Network Modeling Results

Thermal Chimney
Shoulder period - Whole Building Results – NV maintains 1 to 6 ACH during occupied periods.
Summer period - Whole Building Results – NV system maintains ACH above min OA requirements and typically provides 2 ACH.
## Airflow Results (7am to 6pm, Mon-Sat)

<table>
<thead>
<tr>
<th>Zone</th>
<th>Summer Period (Aug 26 – Sep 2)</th>
<th>Winter Period (Jan 7 - 14)</th>
<th>Shoulder Period (May 20 – 26)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Max ACH</td>
<td>Max Airspeed (fpm)</td>
<td>Max ACH</td>
</tr>
<tr>
<td>1.1</td>
<td>5.4</td>
<td>77</td>
<td>7.7</td>
</tr>
<tr>
<td>Kitchen</td>
<td>9.2</td>
<td>36</td>
<td>12.7</td>
</tr>
<tr>
<td>2.3</td>
<td>6</td>
<td>37</td>
<td>7.8</td>
</tr>
<tr>
<td>2.4</td>
<td>33.4</td>
<td>60</td>
<td>25</td>
</tr>
<tr>
<td>2.5</td>
<td>20.1</td>
<td>68</td>
<td>16.1</td>
</tr>
<tr>
<td>2.8</td>
<td>2.8</td>
<td>43</td>
<td>5.7</td>
</tr>
</tbody>
</table>

Maximum airspeeds are all acceptable (<160 fpm) for nearly all spaces so breeze is mostly imperceptible. Zone 1.1 rises slightly above this limit but should not negatively impact comfort (still < 300 fpm)
Sizing the thermal chimney

### Chimney Design Specs

#### Interior solar absorber surface
- **Solar Absorber**
  - Interior heat absorbing surface for solar chimney
  - Source: Other
  - Category: General
  - Region: General
  - Default thickness (in): 0.060
  - Detailed properties: Yes
  - **Thermal Bulk Properties**
    - Conductivity (Btu/in\(\cdot\)h\(\cdot\)F): 2079.000
    - Specific Heat (Btu/lb\(\cdot\)F): 0.08072982
    - Density (lb/ft\(^3\)): 556.0000
    - Resistance (R-value): No
  - **Surface Properties**
    - Thermal absorptance (emissivity): 0.050
    - Solar absorptance: 0.050
    - Visible absorptance: 0.850
    - Roughness: 2-Medium rough
    - **Colour**
      - Blue fabric

#### South facing glazing
- **Sgl Clr 6mm**
  - Source: EnergyPlus dataset
  - Category: Single
  - Region: General
  - **Layers**
    - Number layers: 1
    - Outermost pane: Generic CLEAR 6MM
    - Flip layer: No
  - **Calculated Values**
    - Total solar transmission (SHGC): 0.810
    - Direct solar transmission: 0.775
    - Light transmission: 0.891
    - U-Value (Btu/in\(\cdot\)h\(\cdot\)F): 1.078

### Wall cross section R23
- **Exterior opening**
- **Duct to hallway**

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Solar absorptance should be 85% or higher, product should be able to withstand temperatures of up to 160°F, should be accessible for maintenance and inspection.
CONCEPT:
- Aids comfort ventilation
- Capture the natural breeze and direct it inside the buildings
- The tower inlet is oriented towards the prevailing breezes
- The air isn’t necessary cooled but the circulation creates a fan-like condition
Passive downdraught cooling

CONCEPT:
-Similar to wind catcher, but this is a cooling strategy
-Water is sprinkled at the top of the tower
-When air moves through the tower, the water droplets evaporate picking up the heat the air
-Cool air falls down and enters the building
Passive downdraught cooling
Passive downdraught cooling
Summary

① Focusing on reducing building loads is key to achieving energy efficiency
② This is very much a design issue!
③ This should become a business as usual ‘way of working’
④ Low energy cooling techniques combined with conscious usage is the key to reduce GHG emissions.
Thank You