FAÇADE FOR WIND AND STACK DRIVEN VENTILATION IN TROPICAL HIGH-RISE OFFICE
Content

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Climate of Singapore
Thermal Comfort
Natural ventilation
Concept design
Design collaboration
Final design
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Highrise
High-rise trend

Trendline

Tallest buildings in the world

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Name</th>
<th>City</th>
<th>Country</th>
<th>Height (m)</th>
<th>Floors</th>
<th>Built</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Burj Khalifa★</td>
<td>Dubai</td>
<td>UAE</td>
<td>828 m</td>
<td>163</td>
<td>2010</td>
</tr>
<tr>
<td>2</td>
<td>Shanghai Tower</td>
<td>Shanghai</td>
<td>China</td>
<td>632 m</td>
<td>128</td>
<td>2015</td>
</tr>
<tr>
<td>3</td>
<td>Abraj Al-Bait Clock Tower</td>
<td>Mecca</td>
<td>Saudi Arabia</td>
<td>601 m</td>
<td>120</td>
<td>2012</td>
</tr>
<tr>
<td>4</td>
<td>Ping An Finance Centre</td>
<td>Shenzhen</td>
<td>China</td>
<td>599 m</td>
<td>115</td>
<td>2016 [C]</td>
</tr>
<tr>
<td>5</td>
<td>Goldin Finance 117</td>
<td>Tianjin</td>
<td>China</td>
<td>597 m</td>
<td>117</td>
<td>2016 [C]</td>
</tr>
<tr>
<td>6</td>
<td>Lotte World Tower</td>
<td>Seoul</td>
<td>South Korea</td>
<td>555 m</td>
<td>123</td>
<td>2016 [C]</td>
</tr>
<tr>
<td>7</td>
<td>One World Trade Center</td>
<td>New York City</td>
<td>United States</td>
<td>541 m</td>
<td>104</td>
<td>2014</td>
</tr>
<tr>
<td>8</td>
<td>CTF Finance Centre</td>
<td>Guangzhou</td>
<td>China</td>
<td>530 m</td>
<td>111</td>
<td>2016 [C]</td>
</tr>
<tr>
<td>9</td>
<td>Taipei 101★</td>
<td>Taipei</td>
<td>Taiwan</td>
<td>509 m</td>
<td>101</td>
<td>2004</td>
</tr>
<tr>
<td>10</td>
<td>Shanghai World Financial Center</td>
<td>Shanghai</td>
<td>China</td>
<td>492 m</td>
<td>101</td>
<td>2008</td>
</tr>
</tbody>
</table>
Energy usage office buildings

**Average office**

- HVAC: 33%
- Lighting: 31%
- Fans, pumps & controls: 29%
- 1%

**Office in Singapore**

- HVAC + FAN: 164kWh/m²/year (58%)
- HVAC: 27%
- Lighting: 7%
- Fans, pumps & controls: 4%
- Water system energy: 11%
- Office equipment: 51%

HVAC + FAN: 117kWh/m²/year (39%)
Research question

“How can we design a BUILDING SKIN to maintain a THERMAL COMFORTABLE office with WIND and STACK VENTILATION in a TALL OFFICE BUILDING in a TROPICAL CLIMATE to REDUCE THE COOLING LOAD?”
How do we design a high-rise?
High-rise design strategies

**Naturally ventilated (NV)**
- Small & floorplates
- Occupant manual control
- Small windows, **no solar radiation**
- **External conditions**
- Low energy usage

**Air conditioned (AC)**
- Deep floorplan
- “ceiled glass-box”
- **Complex**, uniform thermal conditions
- **IAQ problems**

**Mixed-Mode (MM)**
- No more than **15m** deep
- **Operable windows**
- Automatic and occupant control
- Energy **Should be** less than AC
- **AC on background**
Test case Singapore
City-state Singapore

Office climate
• International business hub
• Office climate (22°C set point)
• 4.3 million inhabitants
• All urban area (6,929/km²) (NL 393/km²)

Climate characteristics
• High temperatures
• High humidity
• Prevailing wind direction
• Always cloudy
• Rain
Historical climate data Singapore

**Radiation**
- 150 – 480 kWh/m²

**High temperatures**
- Temperature range 24°C - 32°C

**Prevailing wind**
- Avg. 3.2m/s
Thermal comfort
Thermal comfort

Heat exchange

Comfort zone

Comfort zone (±2 – 3°C)
- of PPD10%
- Draught
- Humidity
Comfortable office

Temperature (10% dissatisfied)

Indoor conditions (10% dissatisfied)

temperature + humidity limit

Daily heat peak 11 – 16H

Extra cooling by airflow

Heat accumulation

Extra cooling by airflow

Outdoor = indoor

404

DAYS PER YEAR

COMFORTABLE OFFICE HOURS PER YEAR

INDOOR TEMPERATURE IN RELATION TO OUTDOOR TEMPERATURE

INTRODUCTION - CLIMATE OF SINGAPORE - THERMAL COMFORT - NATURAL VENTILATION - CONCEPT DESIGN - DESIGN COLLABORATION - FINAL DESIGN - DISCUSSION
Natural ventilation
Natural ventilation

Pressure difference

- Building form
- Façade design
- Radiation gradient
- Temperature difference

\[ Q = C_d A_e \left( \frac{2\Delta P}{\rho} \right) \]

Effective surface area

- Windows are more important than wind direction
- Primary pressure losses by ducts
- Secondary pressure losses by obstructions
Design considerations

Local climate
- `urban canyons`
- Wind gradient
- Temperature gradient
- Solar radiance
- Street dimensions

Building form
- Solar shading
- Efficient form
- Air flow pattern
- Segmentation
- Materialisation

Occupancy
- Internal heat load
- Thermal mass
Concept design
Comfortable office with AC reducing façade

Design requirements
- Broad applicable
- Flexible for future changes
- Comfortable
- Cooling load reducing

Design approach
- Bioclimatic design approach
- Natural ventilation
- Cooling load reduction
- Cross ventilation
- Stack ventilation
- Mixed mode concurrent
- Solar shading
- Adaptive thermal comfort
Facade functions

**Main function**

- Separate and filter between nature and interior spaces

**Primary Functions**

- Allow reasonable building methods
- Provide a comfortable interior climate
- Responsible handling in terms of sustainability
- Support use of the building
- Spatial formation of facade

**Secondary Functions**

- Allow transport
- Create reasonable assembly methods
- Create a comfortable temperature
- Create a comfortable humidity level
- Keep climate within a given range
- Minimized energy consumption during use
- Generate energy
- Maintain comfortable climate
- Maintain facade/building value
- Enable faultless use of the building
- Enable architectural possibilities
- Respond to urban context
Concept

Concept steps

Step 1
Sun shading

Step 2
Cross ventilation

Step 3
Solar chimney
Design collaboration
Cooling load reduction

Cooling demand

Demand $Q = \frac{200 \text{W} \cdot (12 \text{ occupants})}{c_{\text{air}} \cdot (T_c - T_{\text{outdoor}})} = \text{m}^3/\text{s}$

$T_{\text{outdoor}}$

$T_c$

HVAC saving hours

<table>
<thead>
<tr>
<th>Categories</th>
<th>NV</th>
<th>NV + fan</th>
<th>NV + AC</th>
<th>AC</th>
<th>Hours without HVAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor</td>
<td>1</td>
<td>$\frac{1}{2}$</td>
<td>$\frac{1}{4}$</td>
<td>0</td>
<td>3650 hrs. (100%)</td>
</tr>
<tr>
<td>Energy required</td>
<td>0</td>
<td>500W</td>
<td>750W</td>
<td>1000W</td>
<td></td>
</tr>
</tbody>
</table>
Combination

adaptable
Final design
Final design

Unitized curtain wall element

Facade elevation & section
Structural

Aluminium construction

2500 PG-Wall system
split mullion

Composition
Airflow control

Facade adaptations

Airflow control
Performance

10%-20%
Dilemma

We cannot solve our problems with the same thinking we used when we created them.

~ Albert Einstein

Comfort  ↔  Energy reduction
Discussion

- This is not the solution for energy reduction. It is managing of the energy reduction.
- The innovative solution that has been found, lamella, chimney, windows are a part of the whole solution.
- Third way, it is not a compromise
- Both parties are included
  - High friction -> lower result
  - 10%PPD, 80%RH limit
Conclusion

- It is not possible to have an office without AC
- Urban canyon is hard to predict
- 16.2% HVAC saving hours is more than expected to be possible.
- Solar shading is effective
- Operable windows are a positive addition
- The addition of the chimney is doubtful according to extra costs, maintenance and structural necessities
- In an other climate or location NV improvements can be made if diurnal differences, higher radiation, lower temperatures, less humid
Recommendation

- Building integrated pv panels
- Daylight collector
- Cable floor air supply
- Windows are more important than wind direction!

<table>
<thead>
<tr>
<th>Opportunity</th>
<th>Identification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexible façade chimney ratio</td>
<td>With aluminum the details stay the same, easy adaptable.</td>
</tr>
<tr>
<td>Daylight savings</td>
<td>Integration of daylight collector in chimney</td>
</tr>
<tr>
<td>Energy productivity</td>
<td>Putting PV’s on the chimney</td>
</tr>
<tr>
<td>Private offices</td>
<td>Via the ceiling the system can still provide natural ventilation via the ceiling and or hollow walls</td>
</tr>
<tr>
<td>Displacement air strategy</td>
<td>If possible the supply of air via the floor to enhance personal controlled airflow, will increase comfort temperature</td>
</tr>
<tr>
<td>City canyon</td>
<td>The façade has potential to function in dense city as the driver is wind.</td>
</tr>
</tbody>
</table>
Further research

- Behavior of induced stack effect in combination with:
  - Friction: Primary pressure losses
  - Photovoltaics
- Behavior of wind in dense urban areas on high-rise facades.
- Influence of open windows on the pressure coefficient. If all the windows are open the effectiveness will reduce due to the lower pressure differences between leeward and windward side.
- Improvement of basic daylight collector with lenses.
- Improvement of local airflow.
- The temperature gradient: temperature at higher levels in dense urban areas in different climates, seasons, humidity levels and temperatures, diurnal differences.
- Resistance in the solar chimney and wind duct (fluid dynamics).
- Personalized air supply designed in furniture to enhance airflow close to the body.
- The integration of a dehumidifying system and the natural ventilation potential. Zoning of the offices. Can the chimneys of one office assist the other office.
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