Sustainable Building Façade and Advanced Fenestration Systems

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(http://www6.cityu.edu.hk/bst/BEET/project_page/index.htm)
Low-Carbon Building (LCB) Technology

- Passive solar design
- Daylight utilization
- Efficient ventilation and airflow strategy
- High performance system equipment
- Energy management and optimization
- Thermal and electric load shifting
- Waste water and heat recovery
- Minimum transportation
- Material recycling and min. embedded energy
Zero-Carbon Building (ZCB) Technology

- Low-carbon building (LCB) technology PLUS Renewable energy sources
  e.g. active solar design, wind energy utilization, biofuel utilization, etc.
Solar wall and water heaters (ZCB)

- Solar chimney

- Wall embedded water piping

- Vacuum-tube water heaters

- Building facade integration for maximum power output

- Energy generation in association with reduced building thermal transmission (reduced air-conditioning load) and heat reflection (reduced UHI effect)
Opaque Facade: BiPV/T (ZCB)

Flat-box aluminum thermal absorber
Invention patent CN 1716642

Building-integrated PV/T

Stand-alone PV/T

Life Cycle Analysis

<table>
<thead>
<tr>
<th></th>
<th>Stand-alone</th>
<th>Building-integrated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payback period (years)</td>
<td>12.1</td>
<td>13.8</td>
</tr>
<tr>
<td>Economical</td>
<td>2.8</td>
<td>3.8</td>
</tr>
<tr>
<td>Energy</td>
<td>3.2</td>
<td>4.0</td>
</tr>
</tbody>
</table>

Glazed Buildings

Extensively-glazed buildings are widely in use

- **Positive** side: transparency; natural brightness; modernity; indoor-outdoor interaction

- **Negative** side: weak thermal element; energy wastage; global warming
Multi-pane window glazing (LCB)

- Air-sealed glazing
- Gas-filled glazing
- Vacuum glazing
- Low-e glazing [IGU]

### Table 2

Energy performance at center of glass of double-glazed vertical windows with 5.7 mm glass panes (10.5 mm for PV laminated glass) and 12.7 mm cavity space (0.12 mm for vacuum space), under steady-state summer conditions: $G=1000 \ W/m^2$; $\theta=60^\circ$; $T_0=33^\circ\text{C}$; $T_s=25^\circ\text{C}$; $h_o=22.7 \ W/m^2\text{K}$; $h_b=8.29 \ W/m^2\text{K}.$

<table>
<thead>
<tr>
<th>Case no.</th>
<th>Glass type</th>
<th>VT</th>
<th>U-factor</th>
<th>SHGC</th>
<th>Outer glass temp (°C)</th>
<th>Inner glass temp (°C)</th>
<th>Room heat gain (W/m²)</th>
<th>Remark</th>
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<tbody>
<tr>
<td>D1</td>
<td>Clear+Air+Clear</td>
<td>0.793</td>
<td>3.035</td>
<td>0.596</td>
<td>37.1</td>
<td>34.9</td>
<td>380</td>
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<tr>
<td>D2</td>
<td>Tinted+Air+Clear</td>
<td>0.476</td>
<td>3.037</td>
<td>0.388</td>
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<td>36.0</td>
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<td>Reflective coating at surface 1</td>
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<td>D3</td>
<td>Reflective on clear+Air+Clear</td>
<td>0.286</td>
<td>3.038</td>
<td>0.273</td>
<td>38.1</td>
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<td>Reflective coating at surface 1</td>
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<td>D4</td>
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<td>0.110</td>
<td>3.038</td>
<td>0.216</td>
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<td>32.7</td>
<td>153</td>
<td>Low-e coating at surface 2; $\varepsilon=0.04$</td>
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<tr>
<td>D5</td>
<td>Low-e on clear+Air+Clear</td>
<td>0.706</td>
<td>1.625</td>
<td>0.303</td>
<td>41.7</td>
<td>30.8</td>
<td>194</td>
<td>Low-e coating at surface 2; $\varepsilon=0.04$</td>
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<td>D6</td>
<td>Low-e on tinted+Air+Clear</td>
<td>0.450</td>
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<td>0.209</td>
<td>48.8</td>
<td>30.5</td>
<td>138</td>
<td>Reflective+low-e coating at surface 2; $\varepsilon=0.04$</td>
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<tr>
<td>D7</td>
<td>Low-e &amp; reflective on clear+Air+Clear</td>
<td>0.274</td>
<td>1.625</td>
<td>0.121</td>
<td>50.6</td>
<td>29.7</td>
<td>85</td>
<td>Low-e coatings at surfaces 2 and 3; $\varepsilon=0.04$</td>
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<tr>
<td>D8</td>
<td>PV laminated glass+Air+Clear</td>
<td>0.095</td>
<td>2.700</td>
<td>0.177</td>
<td>47.3</td>
<td>35.2</td>
<td>127</td>
<td>Electricity generation=25.7W</td>
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<tr>
<td>D9</td>
<td>Clear+Argon+Clear</td>
<td>0.793</td>
<td>2.883</td>
<td>0.598</td>
<td>37.1</td>
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<tr>
<td>D10</td>
<td>Low-e on clear+Argon+Low-e on clear</td>
<td>0.629</td>
<td>0.912</td>
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<td>D11</td>
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<td>0.806</td>
<td>0.222</td>
<td>42.8</td>
<td>31.8</td>
<td>139</td>
<td>Low-e coatings at surfaces 2 and 3; $\varepsilon=0.04$</td>
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</tbody>
</table>

Ultra-violet: 300-400 nm
Visible light: 400-700 nm
Near infra red: 700-2500 nm
New roles of advanced window systems

Two basic principles of ZCB window design for **warm climate zone** to reduce room heat gain:

1. To filter out **infrared** spectrum, but not visible light; and

2. To utilize solar radiation as **renewable** energy source.
See-through Photovoltaic Glazing

Chow TT, Qiu ZZ, Li CY, Solar Energy Materials and Solar Cells, 93, 2009, 230-238.

Monthly cooling load distribution for HK in 4 major directions
PV Ventilated Glazing – with power generation

With semi-transparent a-Si solar cells on glazing:

Advantages: energy saving through electricity generation together with reduction in air-conditioning and artificial lighting

Disadvantage: high investment costs

Predicted monthly cooling loads for 3 different glazing systems in typical open-plan office

Water-flow Window with enclosed loop


Thermosyphon-induced liquid flow up the glazing to the heat exchanger at the top for hot water preheating purpose.

Solar transmission through glazing is reduced and so space cooling load is lowered.

Quality of daylight is enhanced since water affects very little visible light spectrum.

Advantages:
• thermal load reduction;
• daylight utilization; and
• useful heat gain for hot water supply
Full-scale triple-glazed water-flow window at environmental chamber

3 components from outdoor to indoor:

- one layer of clear glazing (12mm thick)
- one layer of flowing water (30mm thick);
- one layer of low-e double glazing (24 mm IGU);

Chow TT, Li CY. Building and Environment, 60, 2013, 44-55.
Experimental results

- Water temperature increase can be > 10°C in the afternoon.
- Water in window circuit kept absorbing heat from the adjacent glass panes and the incident solar radiation during daytime.
- The highest water temperature rise occurred at around 4-5pm.
Performance validation with ESP-r

Double clear glazing with reflective coating at inner glass pane

Chow TT, Li CY, Clarke JA, BS2011, IBPSA Conference, Sydney
Water-flow window performance with application in DHW of Sports Center

- 6 rows of water-flow windows on inclined roof
- Each 29.6m x 1.4m (clear glass with reflective coating)
- DHW demand in line with room opening hours: 7am - 10pm
- Occupant, equipment and lighting operating schedules from Performance-based Building Energy Code Guidelines
- Indoor temperature: 20°C during winter and 24°C during summer
- Feed water temperature same as ambient air temperature; feed rate by gravity or mechanical device.
For a range of feed water flow rates, the year-round space cooling load can be reduced from 22% to 35%.

Within a typical year, more than 20% of the total incident solar energy can be utilized by the DHW system.
**PV/T water-flow window**

- With PV glass pane as the outer pane
  - sc-Si cells laminated between two 6mm clear glazing
  - 15% electricity generation efficiency at STC
  - 88% packing factor

- 30mm water flow cavity

- 12mm clear glass pane as the inner pane

<table>
<thead>
<tr>
<th>Month</th>
<th>Indoor heat gain through PV/T water-flow window (% transmitted)</th>
<th>System thermal efficiency (%)</th>
<th>System electrical efficiency (%)</th>
<th>System integrated efficiency (%)</th>
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<tbody>
<tr>
<td>Jan</td>
<td>6.7</td>
<td>14.7</td>
<td>13.12</td>
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<tr>
<td>Feb</td>
<td>3.8</td>
<td>13.9</td>
<td>13.15</td>
<td>48.5</td>
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<tr>
<td>Mar</td>
<td>9.7</td>
<td>11.1</td>
<td>13.16</td>
<td>45.7</td>
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<tr>
<td>Apr</td>
<td>21.8</td>
<td>6.7</td>
<td>13.15</td>
<td>41.3</td>
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<tr>
<td>May</td>
<td>21.1</td>
<td>8.1</td>
<td>13.14</td>
<td>42.6</td>
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<tr>
<td>Jun</td>
<td>25.8</td>
<td>5.8</td>
<td>13.14</td>
<td>40.4</td>
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<td>Jul</td>
<td>26.3</td>
<td>5.7</td>
<td>13.13</td>
<td>40.2</td>
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<td>Aug</td>
<td>25.2</td>
<td>6.3</td>
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<td>40.9</td>
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<td>Sep</td>
<td>22.4</td>
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<td>Oct</td>
<td>19.2</td>
<td>9.4</td>
<td>13.10</td>
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<tr>
<td>Nov</td>
<td>11.1</td>
<td>12.4</td>
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<td>47.0</td>
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<td>Dec</td>
<td>10.9</td>
<td>13.5</td>
<td>13.13</td>
<td>48.0</td>
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<tr>
<td>Overall</td>
<td>16.4</td>
<td>9.9</td>
<td>13.13</td>
<td>44.5</td>
</tr>
</tbody>
</table>
Conclusion

• Zero carbon building design calls for new roles of opaque facade and window systems

• Innovative facades can utilize large amount of solar energy without occupying extra space

• A range of practical solutions and products are available that carry both passive / active roles

• Water-flow window for example is able to absorb solar heat and reduce indoor heat gain, and so to save AC and DHW electricity consumption without disturbing the indoor visual environment

• More R&D works are in need for new initiatives and full utilization
Thank you