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City University of Hong Kong

CONCRETE SCIENCE ON GLOBAL WARMING:
Role of Building Materials
Global Warming is one of the major concerns in environmental issues.

Its effects are being exposed faster than anticipated recently.

Natural Disasters Report shows that there is an increase in natural disasters with the increase in global temperature.
CONCRETE SCIENCE ON GLOBAL WARMING

Natural disasters report (1900-2006); Source (CRED, 2008)

Global Average Temperature (1860-2000); http://www.ucar.edu
Contributes:

Greenhouse Effect:
Release of greenhouse gases

Urban Heat Island Effect:
Role of Building Materials

GREENHOUSE EFFECT
Greenhouse effect

- The 4th Assessment Report (U. N.'s Intergovernmental Panel on Climate Change (2007) states that after the observation in the middle of 20th century, it is appropriate to define Global Warming was caused by greenhouse gases due to human activities.
- Carbon dioxide (CO₂) emissions since 1750.
- Carbon dioxide is the major composites of greenhouse gases.

Compositions of greenhouse gases

- Carbon Dioxide: 76%
- Methane: 13%
- Nitrous Oxide: 6%
- Fluorocarbons: 5%
The impact of cement on CO₂ emissions

The cement industry contributes 5% of total global carbon dioxide (Marland G, Boden T, Brenkert A. 1998)

China contributes 33% of the global CO₂ emissions from Cement Production (Hendrick C. A., et al., 2004)

That means, the cement industry of China is contributing 1.65% of the total global carbon dioxide
GREENHOUSE EFFECT:

ROLE OF BUILDING MATERIALS

- **Selection** of building materials with low carbon dioxide emissions.

- **Calculation** of total carbon dioxide emissions:

  \[ V \times D \times C = \text{Amount of CO}_2 \text{ emission (kg)} \]

Where as:  
- \( V \) = volume of building material used (m\(^3\))  
- \( D \) = Density of the building material (kg/m\(^3\))  
- \( C \) = Embodied carbon dioxide emission (kg CO\(_2\)/ ton)
Our approach:

- To assess the impact of using the possible Alternative Materials on reduction of CO₂ Emissions in Building Design
GREENHOUSE EFFECT: ROLE OF BUILDING MATERIALS

Ways of possible reduction

- Cement → replaced by PFA, slag cement
- Steel → replaced by recycled steel
- Glass → replaced by cullet glass
- Timber → replaced by plywood

<table>
<thead>
<tr>
<th>Alternative building materials</th>
<th>Weight used in construction (%)</th>
<th>Percentage of CO₂ emission (%)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slag cement</td>
<td>50</td>
<td>-33</td>
<td>(1)</td>
</tr>
<tr>
<td>Recycled steel</td>
<td>40</td>
<td>-35</td>
<td>(2)</td>
</tr>
<tr>
<td>Cullet glass</td>
<td>100</td>
<td>-50</td>
<td>(3)</td>
</tr>
<tr>
<td>Plywood</td>
<td>100</td>
<td>-11</td>
<td>(4)</td>
</tr>
</tbody>
</table>

GREENHOUSE EFFECT:
ROLE OF BUILDING MATERIALS

Conceptual framework on case study

Case Modeling-
Construction of a 28 storeys residential building in Hong Kong

Traditional Building Materials
- Cement
- Steel
- Glass
- Timber

Alternative Building Materials
- PFA, Slag Cement
- Recycled Steel
- Cullet Glass
- Plywood

Embodied Carbon Dioxide Emissions

Overall Reduction in CO₂ Emissions by using the Suggested Alternative Materials
GREENHOUSE EFFECT:

ROLE OF BUILDING MATERIALS

- Floor plan of the target building
GREENHOUSE EFFECT:
ROLE OF BUILDING MATERIALS

- Total volume and weight of the target building

<table>
<thead>
<tr>
<th>Materials</th>
<th>Total Volume (m³)</th>
<th>Density (kg/m³)</th>
<th>Total Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>5792.5</td>
<td></td>
<td>2189565</td>
</tr>
<tr>
<td>Cement</td>
<td>695.1</td>
<td>3150</td>
<td>2189565</td>
</tr>
<tr>
<td>Reinforced Steel</td>
<td>154.1</td>
<td>7850</td>
<td>1209685</td>
</tr>
<tr>
<td>Steel H-pile</td>
<td>2131.1</td>
<td>223</td>
<td>475235</td>
</tr>
<tr>
<td>Glass windows</td>
<td>18.7</td>
<td>3500</td>
<td>65450</td>
</tr>
<tr>
<td>Timber</td>
<td>154.6</td>
<td>550</td>
<td>85030</td>
</tr>
</tbody>
</table>

- Material Inventory and ECO₂ Emissions

<table>
<thead>
<tr>
<th>Materials</th>
<th>Total Weight (tonnes)</th>
<th>ECO₂ Intensity (kg CO₂/t)</th>
<th>Total ECO₂ Emissions (kg CO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>2189.6</td>
<td>820</td>
<td>1795472</td>
</tr>
<tr>
<td>Reinforcement</td>
<td>1209.7</td>
<td>1790</td>
<td>2165363</td>
</tr>
<tr>
<td>Steel H-pile</td>
<td>475.2</td>
<td>1640</td>
<td>779328</td>
</tr>
<tr>
<td>Glass windows</td>
<td>65.5</td>
<td>1126</td>
<td>73753</td>
</tr>
<tr>
<td>Timber</td>
<td>85.0</td>
<td>750</td>
<td>63750</td>
</tr>
</tbody>
</table>
GREENHOUSE EFFECT:
ROLE OF BUILDING MATERIALS

- Summaries of CO₂ reduction of the target building on before and after use of alternative materials

<table>
<thead>
<tr>
<th>Traditional materials</th>
<th>Total ECO₂ Emissions (x10³kg CO₂)</th>
<th>Alternative materials</th>
<th>ECO₂ Reduction (%)</th>
<th>Total ECO₂ Emissions (x10³kg CO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>1795</td>
<td>Slag cement (50%)</td>
<td>-33</td>
<td>1202.7</td>
</tr>
<tr>
<td>Reinforced Steel</td>
<td>2165</td>
<td>Recycled steel (40%)</td>
<td>-35</td>
<td>1407</td>
</tr>
<tr>
<td>Steel H-pile</td>
<td>779</td>
<td>Recycled steel (40%)</td>
<td>-35</td>
<td>506</td>
</tr>
<tr>
<td>Glass windows</td>
<td>73</td>
<td>Cullet glass (100%)</td>
<td>-50</td>
<td>36.5</td>
</tr>
<tr>
<td>Timber</td>
<td>63.8</td>
<td>Plywood (100%)</td>
<td>-11</td>
<td>56.8</td>
</tr>
<tr>
<td><strong>Total CO₂ Emissions</strong></td>
<td><strong>4875.8</strong></td>
<td><strong>Total CO₂ Emissions</strong></td>
<td><strong>3029</strong></td>
<td></td>
</tr>
</tbody>
</table>

- Overall CO₂ Reduction: 1846.8
- Percentage Reduction: 37.9%

The easiest approach in HK is to work on cement content.
GREENHOUSE EFFECT:
ROLE OF BUILDING MATERIALS

Conceptual framework on case study

Case Modeling-
Construction of a 28 storeys residential building in Hong Kong

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Alternative Building Materials
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- Plywood

Embodied Carbon Dioxide Emissions

Overall Reduction in CO₂ Emissions by using the Suggested Alternative Materials
The easiest approach in HK is to work on cement content

**ECO$_2$ Intensity of Different Cement:**

<table>
<thead>
<tr>
<th>Material</th>
<th>ECO$_2$ Intensity (kg CO$_2$/t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>820</td>
</tr>
<tr>
<td>PFA</td>
<td>585</td>
</tr>
<tr>
<td>Slag cement</td>
<td>279</td>
</tr>
</tbody>
</table>

(Source Hammond, G. and Jones, C., 2006)

**Comparison of mix proportion used in HK (Apply to a typical building)**

<table>
<thead>
<tr>
<th>Mix Proportion</th>
<th>Overall kg of CO$_2$ (x10$^3$)</th>
<th>% of reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% cement</td>
<td>1795</td>
<td></td>
</tr>
<tr>
<td>75% cement+25% PFA</td>
<td>1653</td>
<td>-7.9%</td>
</tr>
<tr>
<td>67% cement+33% PFA</td>
<td>1608</td>
<td>-10.5%</td>
</tr>
<tr>
<td>50% cement+50% slag</td>
<td>1203</td>
<td>-33.0%</td>
</tr>
<tr>
<td>30% cement+70% slag</td>
<td>966</td>
<td>-46.2%</td>
</tr>
</tbody>
</table>

Think about !!! ACT !!!!
# GREENHOUSE EFFECT:

## ROLE OF BUILDING MATERIALS

### Overall kg of CO$_2$ (x10$^3$) % of reduction

<table>
<thead>
<tr>
<th>Mix</th>
<th>Combination</th>
<th>Cement (kg)</th>
<th>GGBS (kg)</th>
<th>CO2 equivalent</th>
<th>% reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100% OPC</td>
<td>390</td>
<td>-</td>
<td>320</td>
<td>--</td>
</tr>
<tr>
<td>2</td>
<td>30% GGBS</td>
<td>291</td>
<td>124</td>
<td>273</td>
<td>-14.6</td>
</tr>
<tr>
<td>3</td>
<td>50% GGBS</td>
<td>185</td>
<td>185</td>
<td>203</td>
<td>-36.4</td>
</tr>
<tr>
<td>4</td>
<td>70% GGBS</td>
<td>117</td>
<td>273</td>
<td>172</td>
<td>-46.2</td>
</tr>
<tr>
<td>5</td>
<td>80% GGBS</td>
<td>96</td>
<td>384</td>
<td>186</td>
<td>-41.9</td>
</tr>
</tbody>
</table>

**Example:** Concrete Mix of Same Grade 35 (Grade 35)

- **Think about !!! ACT !!!!**
Role of Building Materials

URBAN HEAT ISLAND EFFECT
Urban Heat Island (UHI) Effect:
- A kind of climatic change with increase in urban temperatures.
- An urban area in which the temperature is significantly higher than its surrounding rural area.

Influences of UHI:
- Increase the discomfort (Hassid et al., 2001)
- Higher pollution levels (Hassid et al., 2001)
- Increase electricity demand for cooling (Santamouris, 2001)
- Decrease the efficiency of air conditioners (Santamouris, 2001)

Causes of UHI:
- High population density
- Increase in number of high-rise buildings
- Low reflective surfaces of building materials that absorb more heat from the sun
- Less vegetation which provide shade and cool the air.
- Street Canyon Situation
Street Canyon Situation:

+ A canyon (a deep narrow valley) formed in a street between two rows of buildings which trapped the fumes exhausted by vehicles (Ref: Hongkong Industrialist, 2007)

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Street Canyon Situation:

+ A canyon (a deep narrow valley) formed in a street between two rows of buildings which trapped the fumes exhausted by vehicles (Ref: Hongkong Industrialist, 2007)

```

- **Urban Heat Island Effect**
  - Heat release slowly from building materials
  - Temperature increase

- **Street Canyon Effect**
  - Air pollutants recirculate within the canyon
  - Tall Building

- **Highly unsustainable environment**
  - Hot harmful plume
  - Tall Building

```
Urban Heat Island Effect

Roof level wind

Air pollutants recirculate within the canyon

Tall Building

Hot harmful plume

Tall Building

a. Urban Heat Island Effect

b. Street Canyon Effect

c. Highly unsustainable environment

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URBAN HEAT ISLAND EFFECT:
ROLE OF BUILDING MATERIALS

- **Mitigation techniques:**
  - Improve building design to enhance ventilation
    - Green roofs (*Hui, S. C. M.*, 2006; *Architectural Services Department, Feb 2007*)
  - Promote the use of environmentally friendly building materials
    - Use lightly colored and high solar reflectance and heat emittance

- **Selection of appropriate materials for building finishes:**
  - Low energy loaded building materials
  - Low ECO₂ materials
Our approach:

- To assess the contribution of building finishes materials on UHI
- To characterise building finishes materials in terms of their total energy released after heat
Modes of heat transfer:

- **Conduction** = $q_k = -kA\frac{dT}{dx}$, in x-direction,
  - $A$ = surface area,
  - $k$ = thermal conductivity of the material

- **Convection** = $q_c = \overline{h}A(T_s-T_F)$
  - $T_s$ = surface temperature,
  - $\overline{h}$ = convection coefficient (related to the environment)

- **Radiation** = $q_r = \overline{h}_rA(T_a-T_b)$
  - $T_a$ = Temp. of surface a, Temp. of surface b,
  - $\overline{h}_r$ = radiation coefficient (related to the shape of the object)
URBAN HEAT ISLAND EFFECT:
FOUR BUILDING MATERIALS

- Our work: compared 4 basic finishes materials
For simplicity, the heat transfer mechanism can be considered as one-dimensional problem under unsteady heat transfer condition. The surface convection rate is (Maldague, X.P., 2001):

$$q_c = hA(T_s - T_F) = hA(T_s - T_F)e^{(-hA t/\rho Vc)}$$

The equation of transient solid temperature for time-dependent surface heat transfer rate,

$$T_s(t) = T_{F,\infty} + [T_s(t=0) - T_{F,\infty}]e^{(-hA t/\rho Vc)}$$
Simulated surface temperature evolution of a concrete sample:

\[ T_s(t) = T_{F,\infty} + [T_s(t=0)- T_{F,\infty}]e^{-\left(\frac{hA t}{\rho V_c}\right)} \]

(1) Rate of cooling:
- Slope of the cooling curve.

(2) Total Energy Delivered:
- The energy transferred \( Q \) can be derived by performing time integration over a length of time \( \tau \). (L. C. Thomas, 1980, p.99, eq. (2-137):

\[ Q = \rho V_c[T_s(t=0)- T_{F,\infty}][1-e^{-\left(\frac{hA t}{\rho V_c}\right)}] \]
Total Energy Released:

- The energy transferred $Q$ can be derived by performing time integration over a length of time $\tau$. Or time $t \rightarrow \infty$.

- (L. C. Thomas, 1980, p.99, eq. (2-137)):

$$Q = \rho V c [T_s(t=0) - T_{F,\infty}] [1 - e^{-\frac{h A T}{\rho V c}}]$$
Urban Heat Island Effect: Four Building Materials

- Heat up with oven
- Surface temperature are recorded by infrared camera with capturing frequency of 1/120 sec.
URBAN HEAT ISLAND EFFECT: FOUR DIFFERENT MATERIALS

- Cooling pattern of different finishing materials
URBAN HEAT ISLAND EFFECT:
FOUR DIFFERENT MATERIALS

- Comparison between simulation vs experimental data

![Cooling Curve of Different Finishing Materials](image1)

![Simulated Cooling Curve of Different Finishing Materials](image2)
(1) Rate of cooling:
- Slope of the cooling curve.

Diagram: Cooling Rate of Different Finishing Materials

- Ceramic
- Clay
- Marble
- Concrete

Stage I
Stage II
(1) Rate of cooling:

- At stage I:
  - Cooling rate of: ceramic > clay > marble > concrete
    - It means that ceramic is more responsive to the change in the surrounding temperature.

- At stage II:
  - Cooling rate of: concrete > marble > clay > ceramic
    - It is because the energy inside ceramic/clay is released at stage I, hence the temperature difference is lower between ceramic and the surrounding temp. Therefore, the cooling rate of ceramic started to slow down and even slower than concrete.
(2) Total energy released:

Area = 1104.52°C

Area = 1130.97°C

Area = 1163.74°C

Area = 1194.75°C
**URBAN HEAT ISLAND EFFECT: SUMMARY**

- Total energy released the four different building finishing materials:

<table>
<thead>
<tr>
<th></th>
<th>Concrete</th>
<th>Marble</th>
<th>Clay</th>
<th>Ceramic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. cooling rate</td>
<td>-0.0063</td>
<td>-0.0070</td>
<td>-0.0072</td>
<td>-0.0089 [ceramic cool fast]</td>
</tr>
<tr>
<td>Total energy</td>
<td>1194.75</td>
<td>1163.74</td>
<td>1130.97</td>
<td>1104.52</td>
</tr>
</tbody>
</table>
### URBAN HEAT ISLAND EFFECT: ROLE OF BUILDING MATERIALS

<table>
<thead>
<tr>
<th></th>
<th>Concrete</th>
<th>Marble</th>
<th>Clay</th>
<th>Ceramic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean cooling rate of stage I</td>
<td>-0.0063</td>
<td>-0.0070</td>
<td>-0.0072</td>
<td>-0.0089 [ceramic cool fast]</td>
</tr>
<tr>
<td>Total energy</td>
<td>1194.75</td>
<td>1163.74</td>
<td>1130.97</td>
<td>1104.52</td>
</tr>
</tbody>
</table>

Parameters need further study: colour, reflectives? performance under street environment?

a. Urban Heat Island Effect
b. Street Canyon Effect
c. Highly unsustainable environment
Further work

Materials Index for Environmentally Sustainable Building Finishes

**Thermal emissivity Measurement by IR scanning**

- Lab. Controlled Test (under Environmental Conditions)
- Site Testing (Façade with similar and different aspect ratios, different materials, colour and on-site ambient temperature)

**Construction of Material Classification Index and UHI model**

Extent of its potential contributions to the UHI
CONCRETE SCIENCE ON GLOBAL WARMING:
Role of Building Materials

Thank You!!