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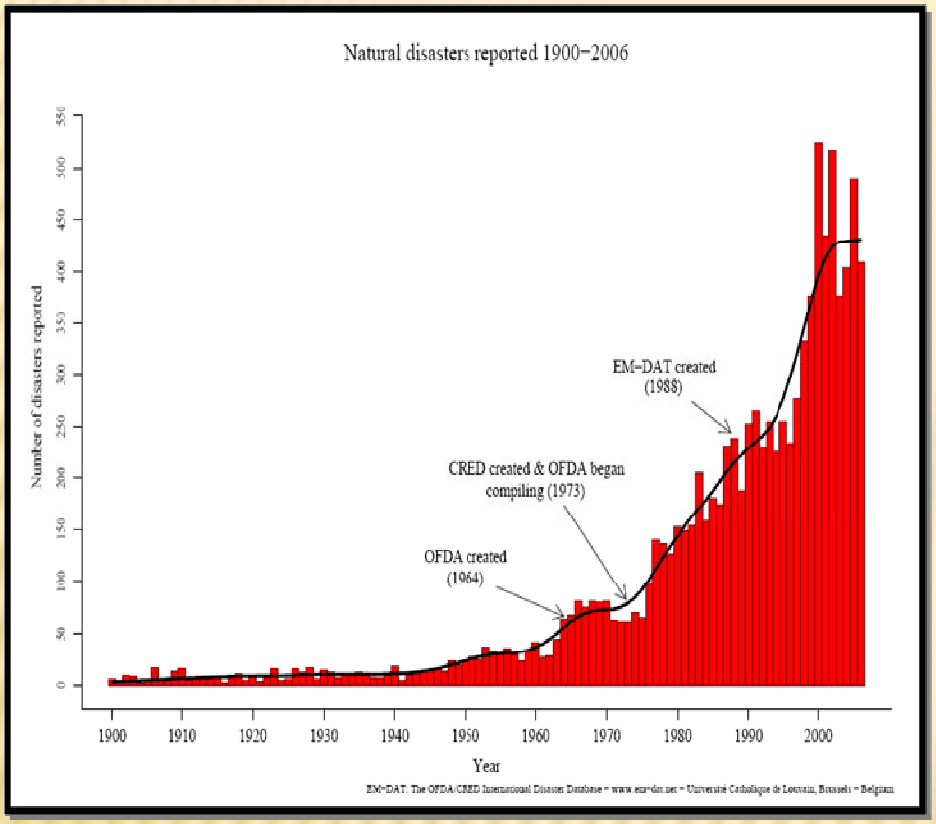
CONCRETE SCIENCE ON GLOBAL WARMING:

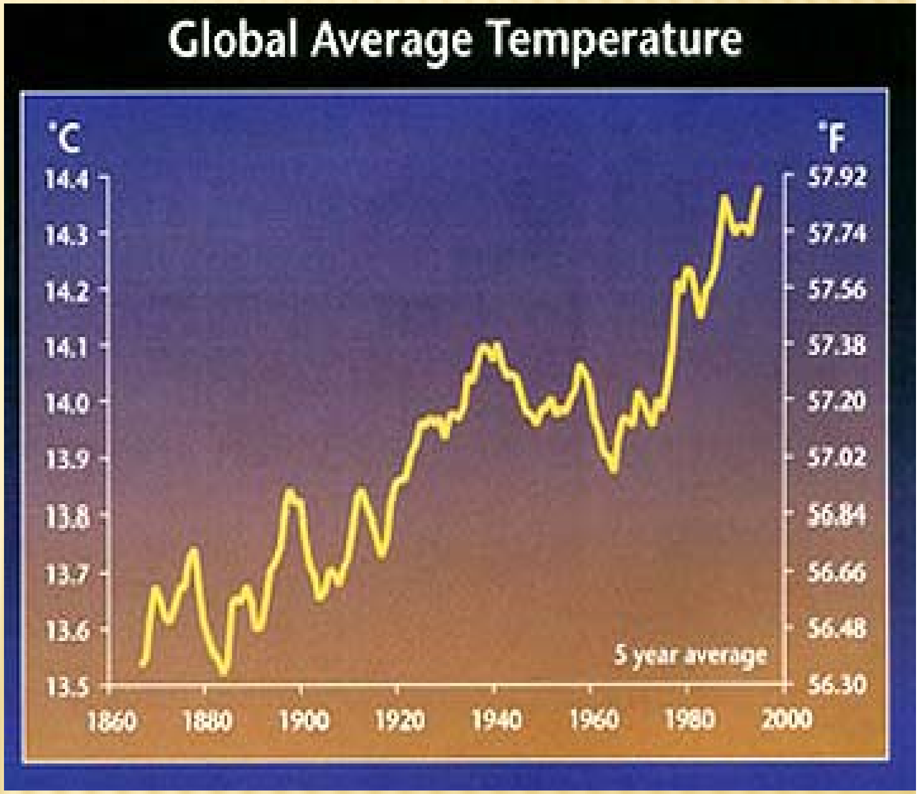
Role of Building Materials

CONCRETE SCIENCE ON GLOBAL WARMING

- 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

CONCRETE SCIENCE ON GLOBAL WARMING

- **Contributes:**

Greenhouse Effect:
Release of greenhouse gases

Urban Heat Island Effect:

Global Warming

Role of Building Materials

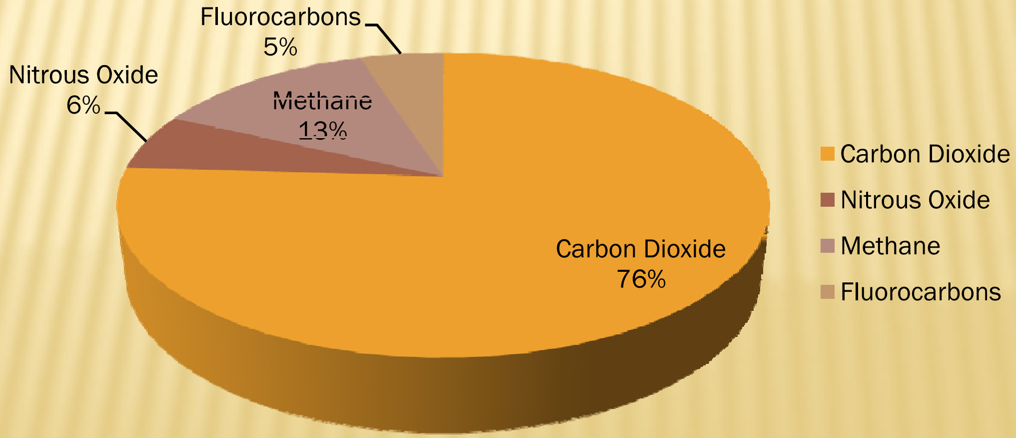
GREENHOUSE EFFECT

GREENHOUSE EFFECT :

ROLE OF BUILDING MATERIALS

- 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 (CO_2) emissions since 1750.
  - Carbon dioxide is the major composites of greenhouse gases.

Compositions of greenhouse gases

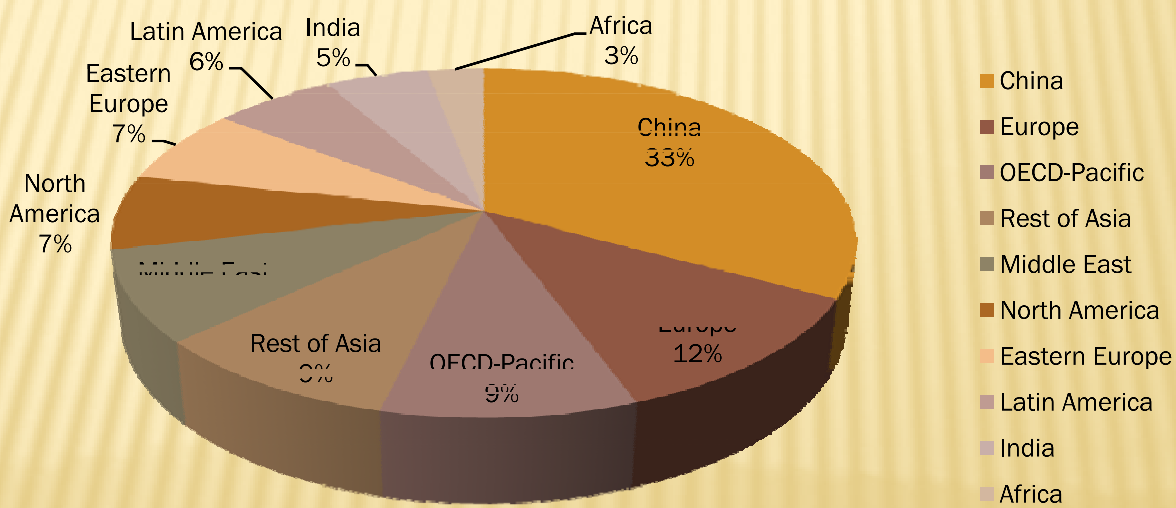


GREENHOUSE EFFECT :

ROLE OF BUILDING MATERIALS

- The impact of cement on CO_2 emissions
- The cement industry contributes 5% of total global carbon dioxide (Marland G, Boden T, Brenkert A. 1998)
- China contributes 33% of the global CO_2 emissions from Cement Production (Hendrick C. A., et al., 2004)

Global Carbon Dioxide Emissions from Cement Production



- 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)

GREENHOUSE EFFECT :

ROLE OF BUILDING MATERIALS

- Our approach :

  - To assess the impact of using the possible Alternative Materials on reduction of CO_2 Emissions in Building Design

GREENHOUSE EFFECT :

ROLE OF BUILDING MATERIALS

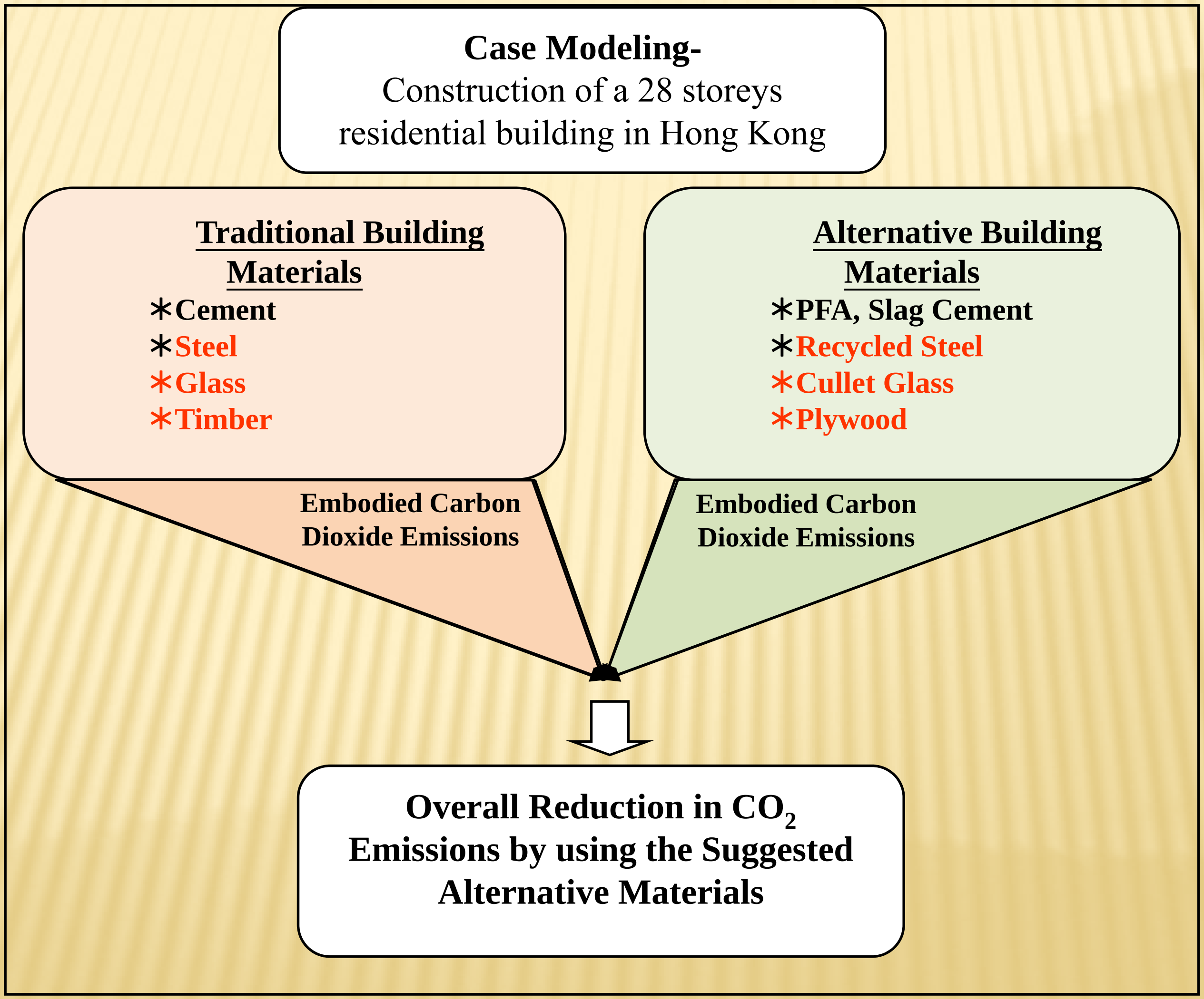
- **Ways of possible reduction**
  - Cement → replaced by PFA, slag cement
  - Steel → replaced by recycled steel
  - Glass → replaced by cullet glass
  - Timber → replaced by plywood

Alternative building materials	Weight used in construction (%)	Percentage of CO_2 emission (%)	References
Slag cement	50	-33	(1)
Recycled steel	40	-35	(2)
Cullet glass	100	-50	(3)
Plywood	100	-11	(4)

[1] Slag Cement Association, 2003.
[2] Gill, B. and Manchanda, S., 2006.
[3] Saint-gobain Group, 2008.
[4]The Institute of Structural Engineers, 1999.

GREENHOUSE EFFECT : ROLE OF BUILDING MATERIALS

- Conceptual framework on case study



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

	Total Volume (m^3)	Density (kg/m^3)	Total Weight (kg)

- Material Inventory and ECO_2 Emissions

Materials	Total Weight (tonnes)	ECO_2 Intensity ($kg\ CO_2/t$)	Total ECO_2 Emissions ($kg\ CO_2$)
Cement	2189.6	820	1795,472
Reinforcement	1209.7	1790	2165,363
Steel H-pile	475.2	1640	779,328
Glass windows	65.5	1126	73,753
Timber	85.0	750	63,750

GREENHOUSE EFFECT :
ROLE OF BUILDING MATERIALS

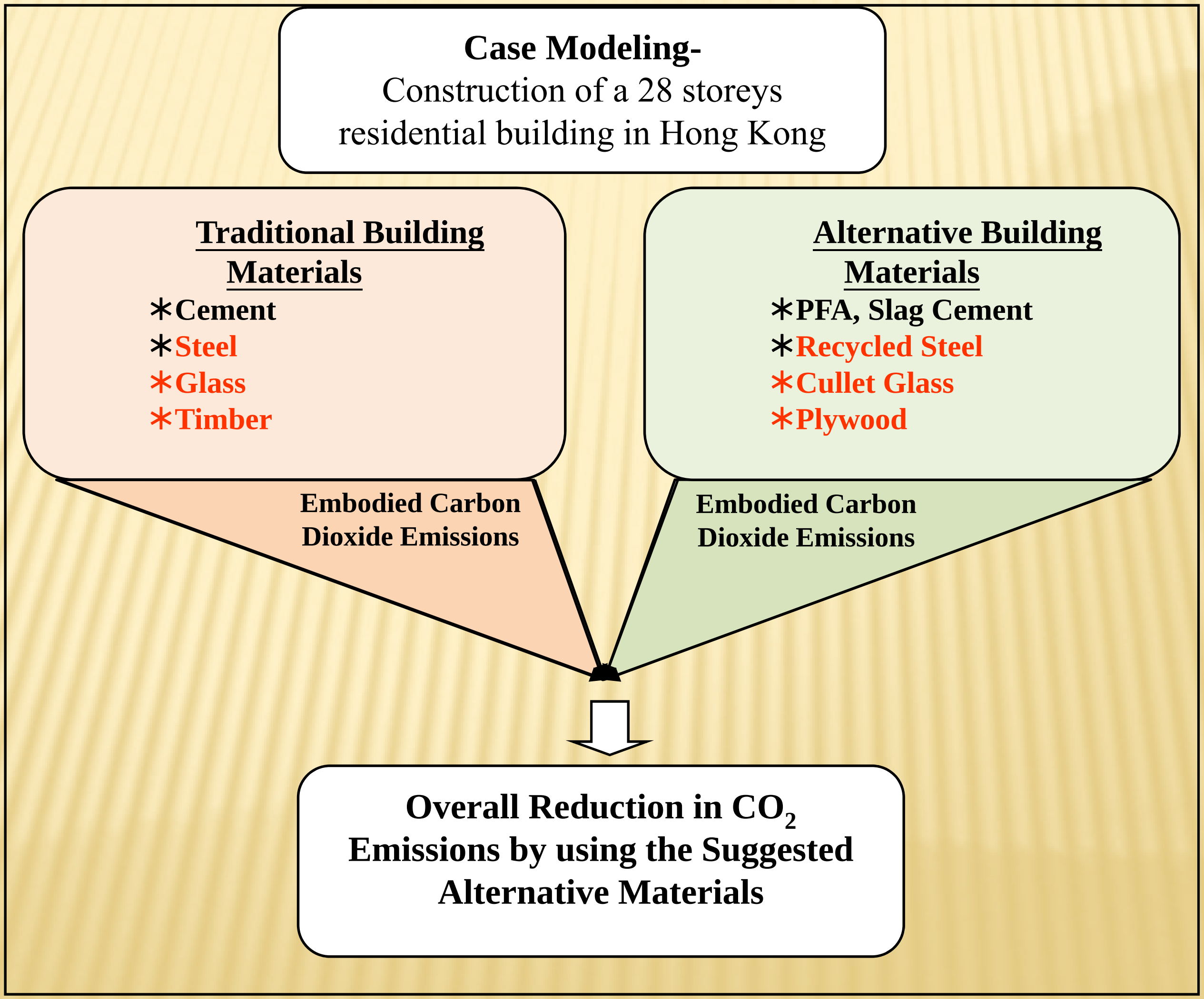
- Summaries of CO_2 reduction of the target building on before and after use of alternative materials

Traditional materials	Total ECO_2 Emissions ($\times 10^3$kg CO_2)	Alternative materials	ECO_2 Reduction (%)	Total ECO_2 Emissions ($\times 10^3$ kg CO_2)
Cement	1795	**Slag cement (50%)**	-33	1202.7
Reinforced Steel	2165	**Recycled steel (40%)**	-35	1407
Steel H-pile	779	**Recycled steel (40%)**	-35	506
Glass windows	73	**Cullet glass (100%)**	-50	36.5
Timber	63.8	**Plywood (100%)**	-11	56.8
Total CO_2 Emissions	**4875.8**	**Total CO_2 Emissions**		**3029**
		Overall CO_2 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



GREENHOUSE EFFECT : ROLE OF BUILDING MATERIALS

The easiest approach in HK is to work on cement content

ECO$_2$ Intensity of Different Cement:

	ECO$_2$ Intensity (kg CO$_2$/t)
Cement	820
PFA	585
Slag cement	279

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

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

	Overall kg of CO$_2$ (x10^3)	% of reduction
100% cement	1795	
75% cement+25% PFA	1653	-7.9%
67% cement+33% PFA	1608	-10.5%
50% cement+50% slag	1203	-33.0%
30% cement+70% slag	966	-46.2%

Think about !!! ACT !!!!

GREENHOUSE EFFECT :

ROLE OF BUILDING MATERIALS

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e.g Concrete Mix of Same Grade 35 (Grade 35)

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

Think about !!! ACT !!!!

Role of Building Materials

URBAN HEAT ISLAND EFFECT

URBAN HEAT ISLAND EFFECT: ROLE OF BUILDING MATERIALS

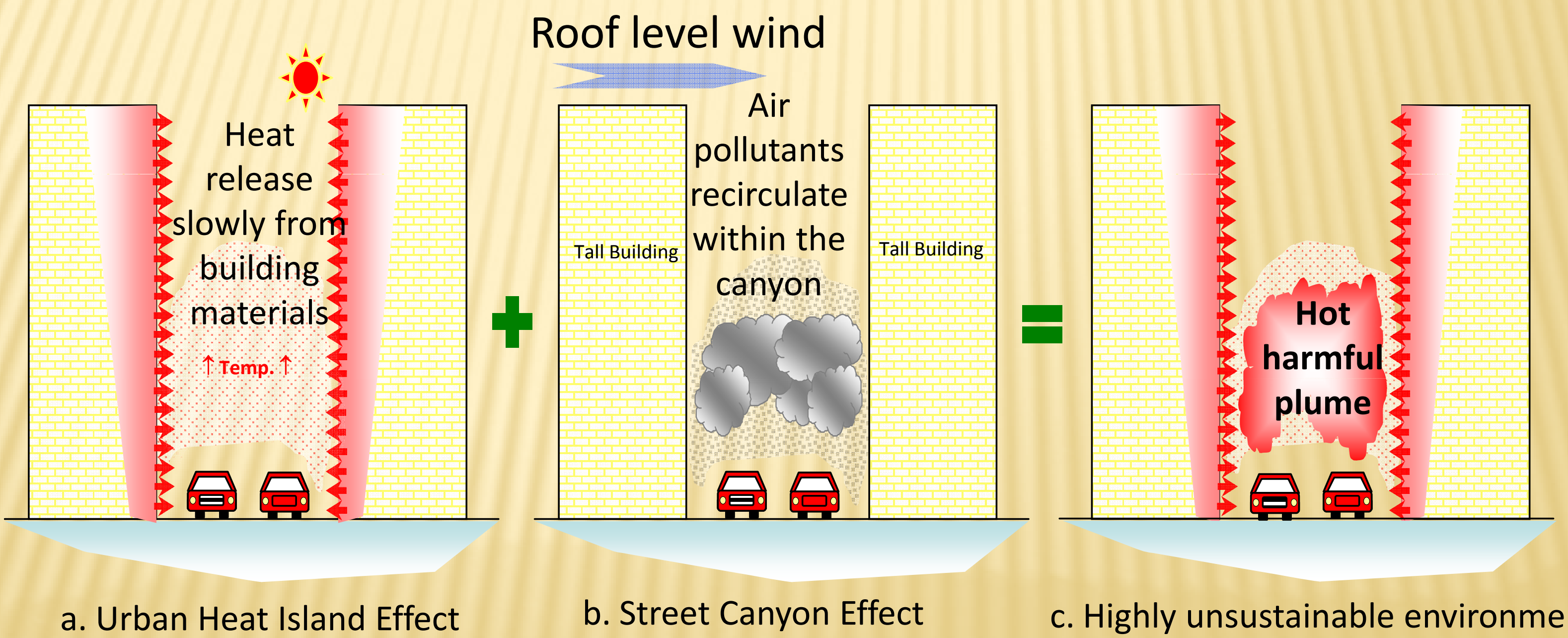
- Urban Heat Island (UHI) Effect:
  - A kind of climatic change with increase in urban temperatures.
  - An urban area in which the temperature is significantly higher than its surrounding rural area.

- 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

URBAN HEAT ISLAND EFFECT: ROLE OF BUILDING MATERIALS

- **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: 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 (*Harman, I.N. & Belcher, S.E. 2007; Akbari, H., S. et al., 1993.)*
- Selection of appropriate materials for building finishes:
  - Low energy loaded building materials
  - Low ECO_2 materials

URBAN HEAT ISLAND EFFECT: ROLE OF BUILDING MATERIALS

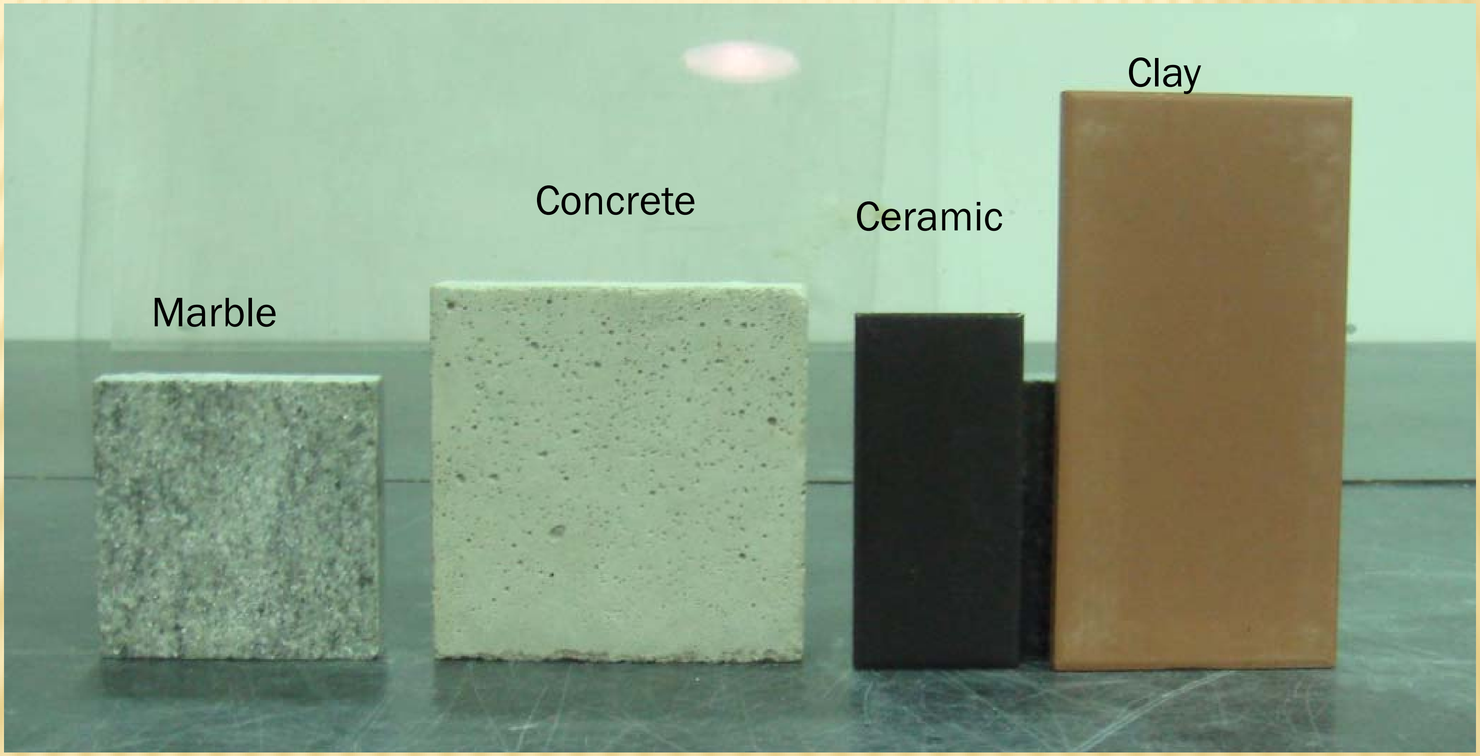
- Our approach :
  - To assess the contribution of building finishes materials on UHI
  - To characterise building finishes materials in terms of their total energy released after heat

URBAN HEAT ISLAND EFFECT: HEAT TRANSFER MODES

- Modes of heat transfer:
  - **Conduction** = q_k = $-kA(dT/dx)$,
    in x-direction,
    A=surface area,
    k = thermal conductivity of the material
  - **Convection** = q_c= $ħA(T_s-T_F)$
    T_s = surface temperature,
    ħ = convection coefficient (related to the environment)
  - **Radiation** = q_r = $ħ_r A(T_a-T_b)$,
    T_a = Temp. of surface a, Temp. of surface b,
    $ħ_r$ =radiation coefficient (related to the shape of the object)

URBAN HEAT ISLAND EFFECT: FOUR BUILDING MATERIALS

- Our work: compared 4 basic finishes materials



URBAN HEAT ISLAND EFFECT: UNSTEADY HEAT TRANSFER

- 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.*) :

$$q_c = \hbar A(T_s - T_F) = \hbar A(T_s - T_F)e^{(-\hbar A t/\rho V c)}$$

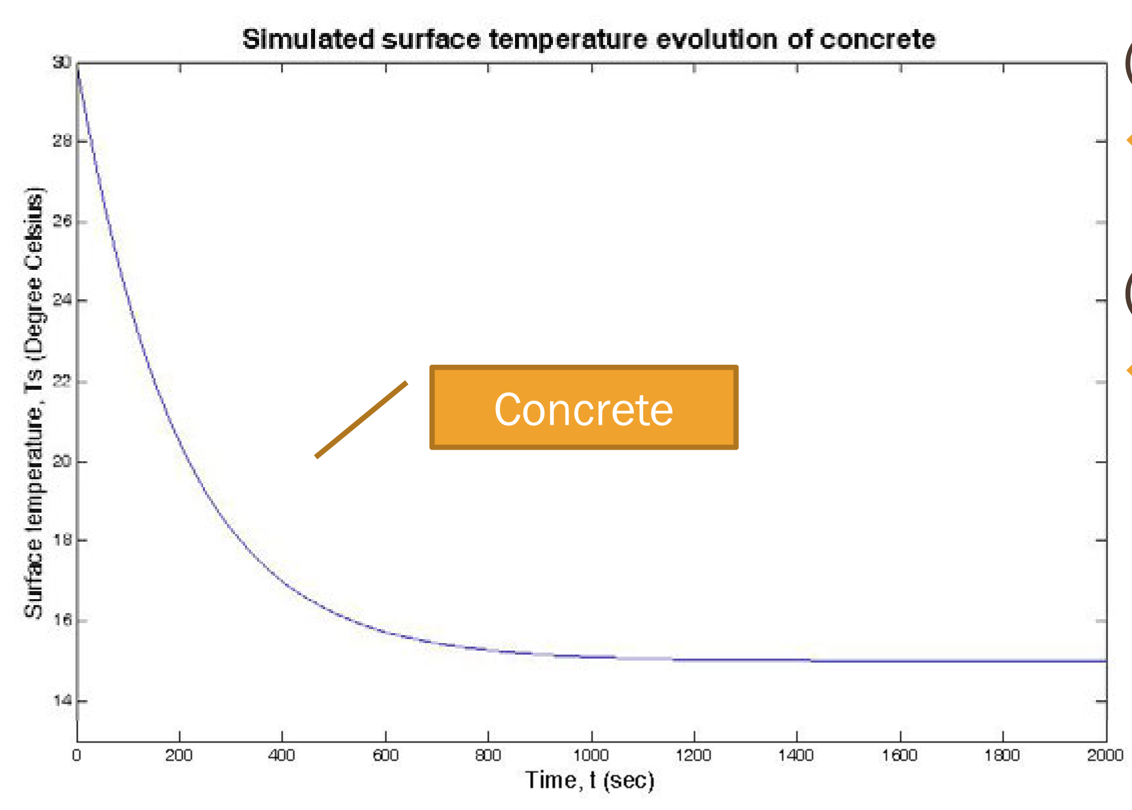
- The equation of transient solid temperature for time-dependent surface heat transfer rate,

$$T_s\,(t) = T_{F,\infty} + [T_s(t=0) - T_{F,\infty}]e^{-\,(-\hbar A t/\rho V c)}$$

URBAN HEAT ISLAND EFFECT: UNSTEADY HEAT TRANSFER

- Simulated surface temperature evolution of a concrete sample:

$$T_s\ (t) = T_{F,\infty} + [T_s(t=0) - T_{F,\infty}]e^{-(-\hbar A t/\rho V c)}$$



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

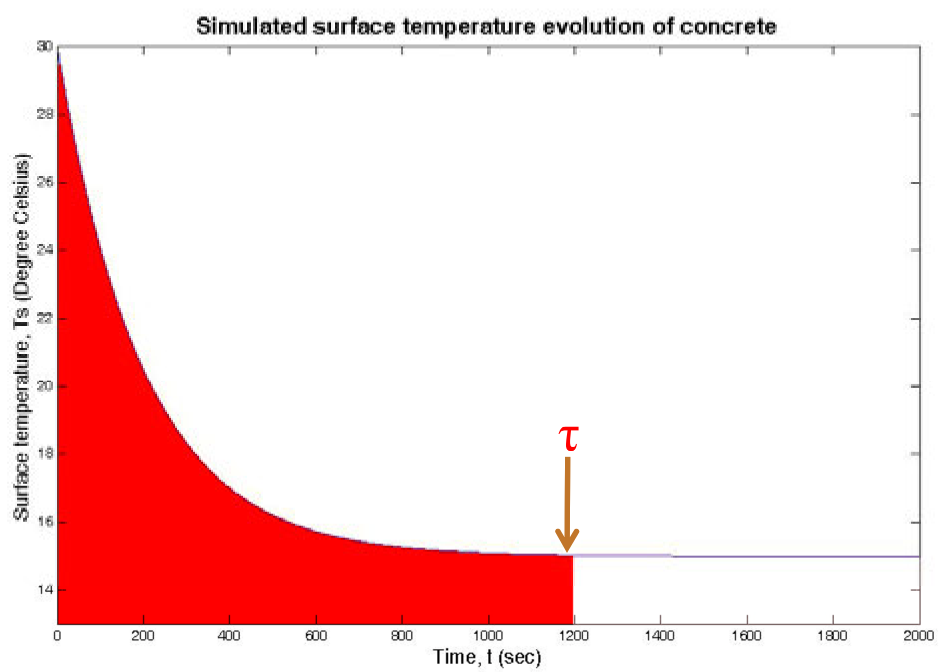
$$Q = \rho Vc[T_s(t=0) - T_{F,\infty}][1 - e^{(-\hbar A \tau/\rho Vc)}]$$

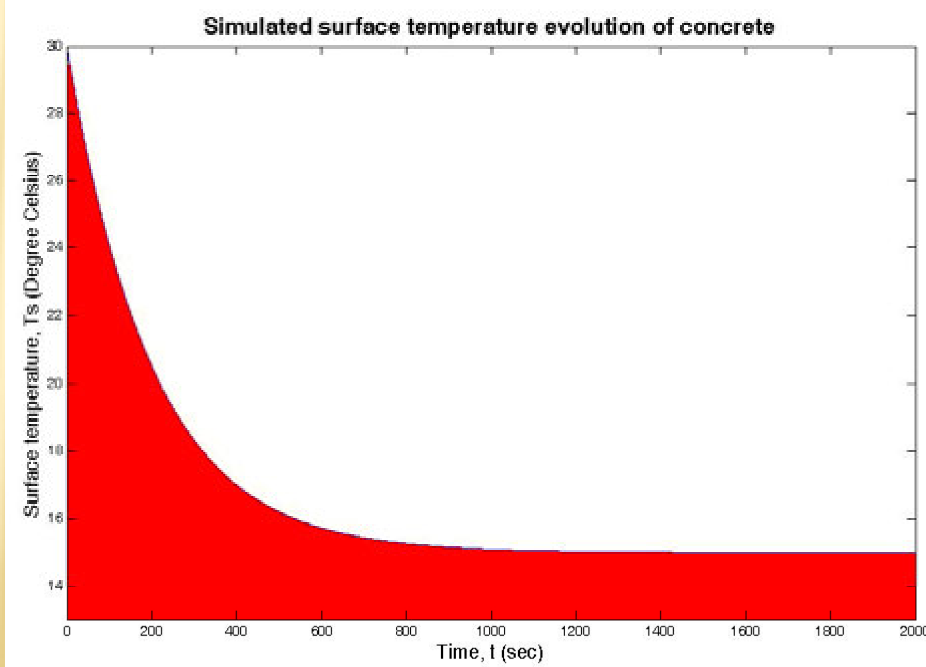
URBAN HEAT ISLAND EFFECT: TOTAL ENERGY RELEASED

Total Energy Released:

- The energy transferred Q can be derived by performing time integration over a length of time τ. *Or* time t→ ∞.
- *(L. C. Thomas, 1980, p.99, eq. (2-137):*

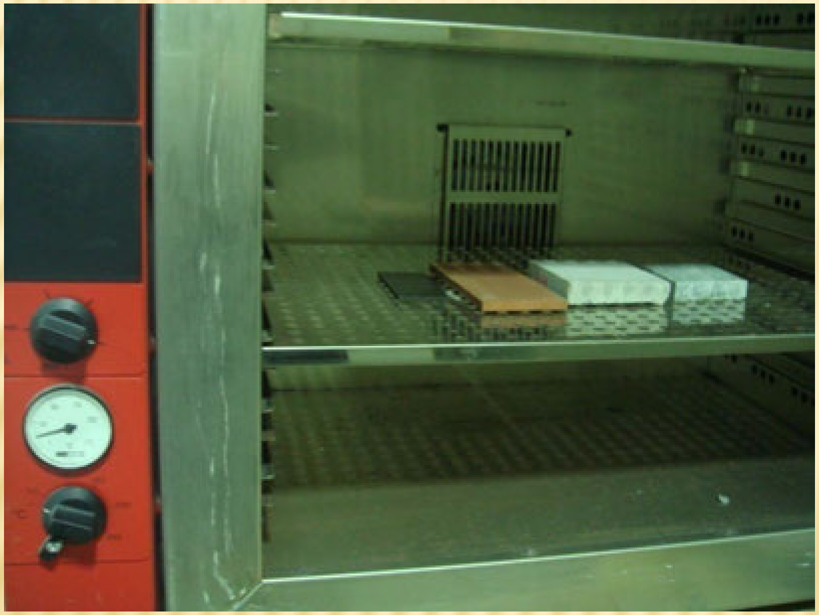
$$Q = \rho Vc[T_s(t=0) - T_{F,\infty}][1-e^{(-\hbar A\tau/\rho Vc)}]$$





URBAN HEAT ISLAND EFFECT: FOUR BUILDING MATERIALS

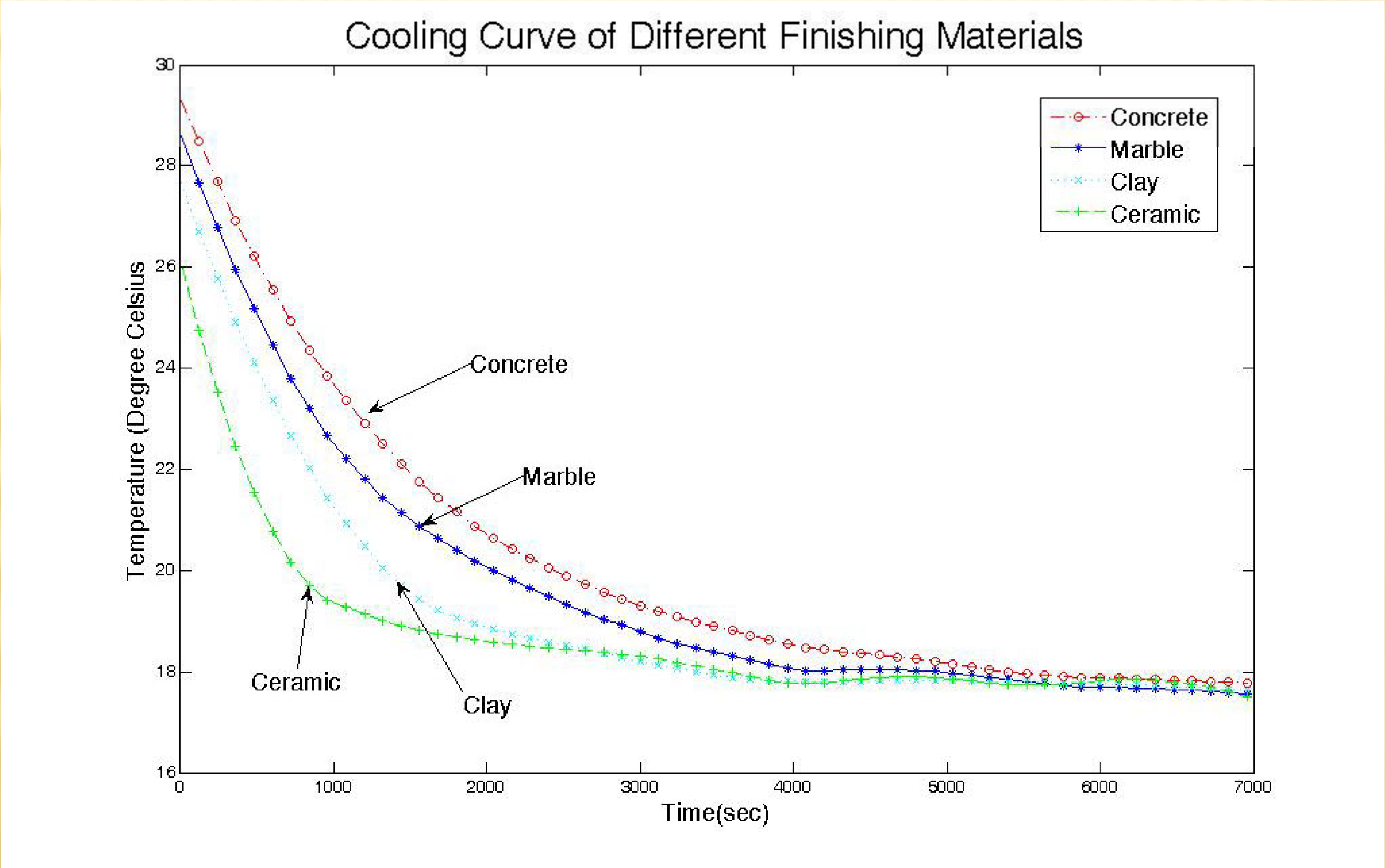
- Heat up with oven



- Surface temperature are recorded by infrared camera with capturing frequency of 1/120 sec.

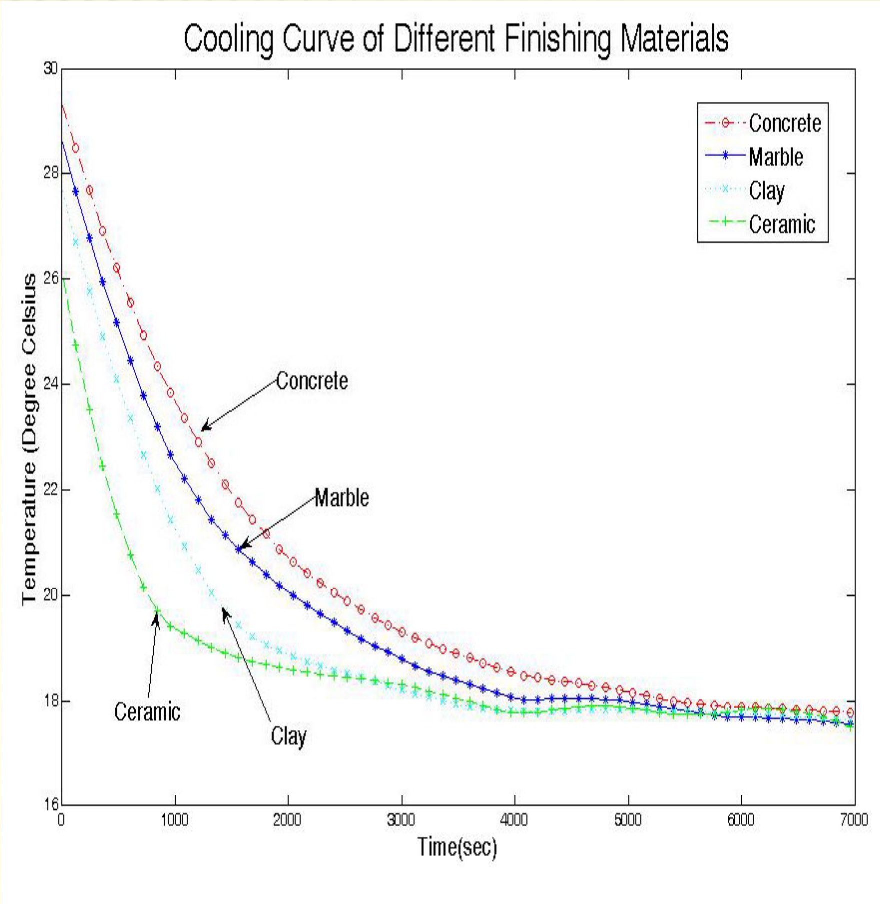
URBAN HEAT ISLAND EFFECT: FOUR DIFFERENT MATERIALS

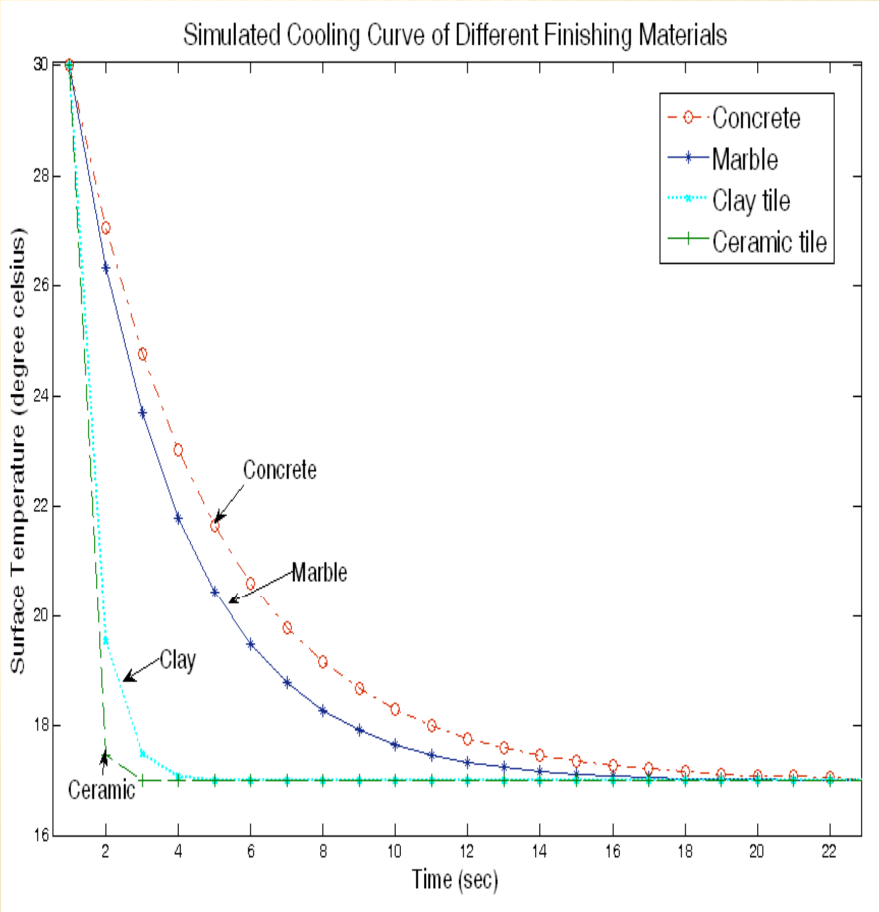
- Cooling pattern of different finishing materials



URBAN HEAT ISLAND EFFECT: FOUR DIFFERENT MATERIALS

- Comparison between simulation *vs* experimental data

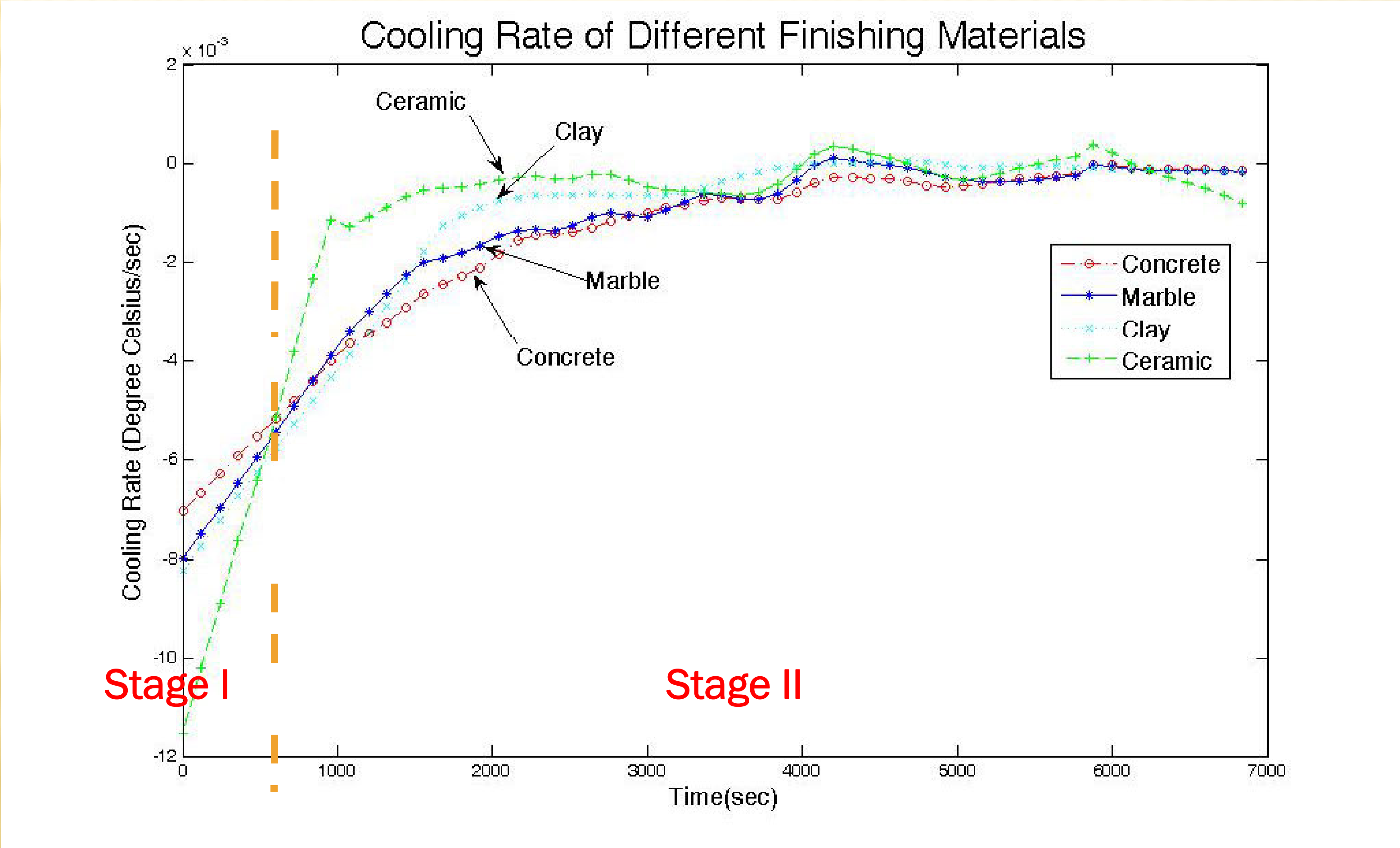




URBAN HEAT ISLAND EFFECT: RATE OF COOLING

(1) Rate of cooling:

- Slope of the cooling curve.



URBAN HEAT ISLAND EFFECT: RATE OF COOLING

(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.

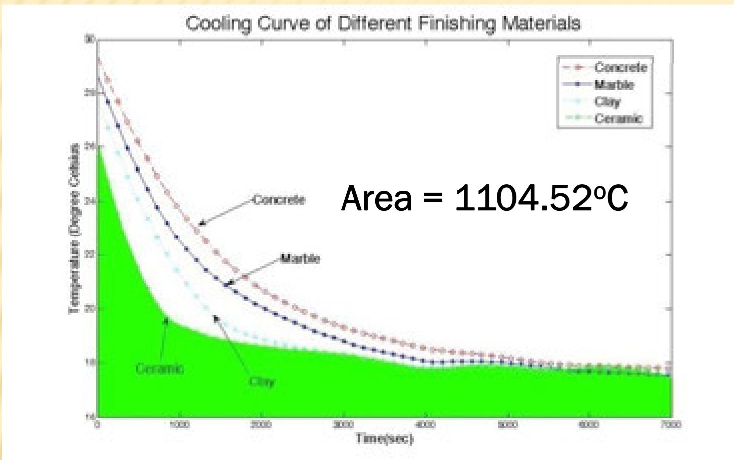
- At stage II:
  - Cooling rate of:

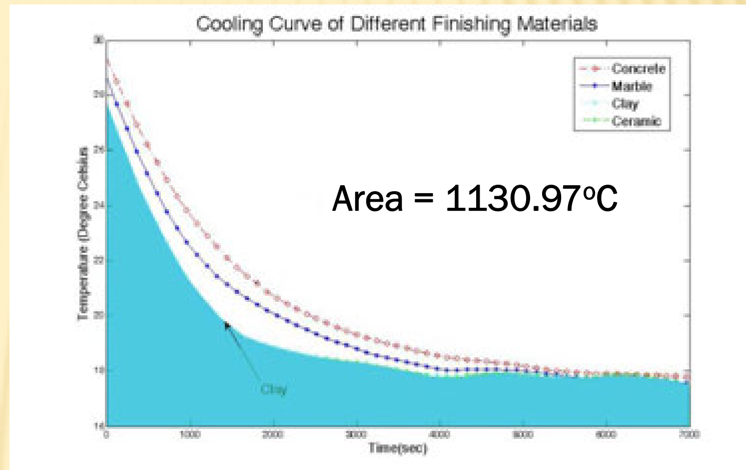
    concrete > marble > clay > ceramic

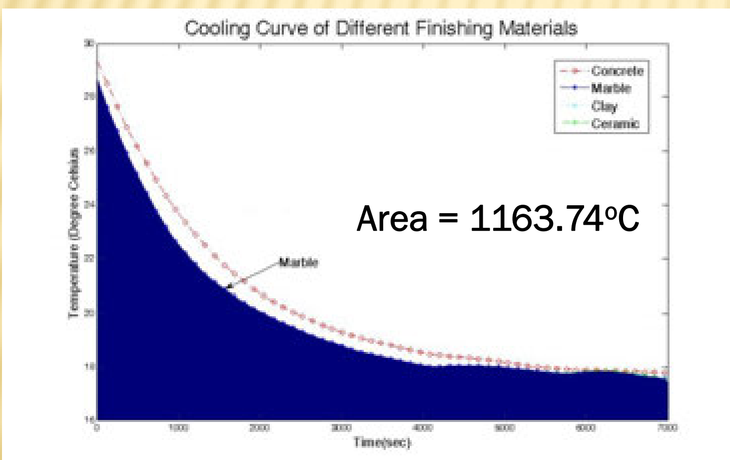
  - It is because the energy inside ceramic/clay is released at stage I, hence the temperature difference is lower between ceramic and the surrounding temp. Therefore, the cooling rate of ceramic started to slow down and even slower than concrete.

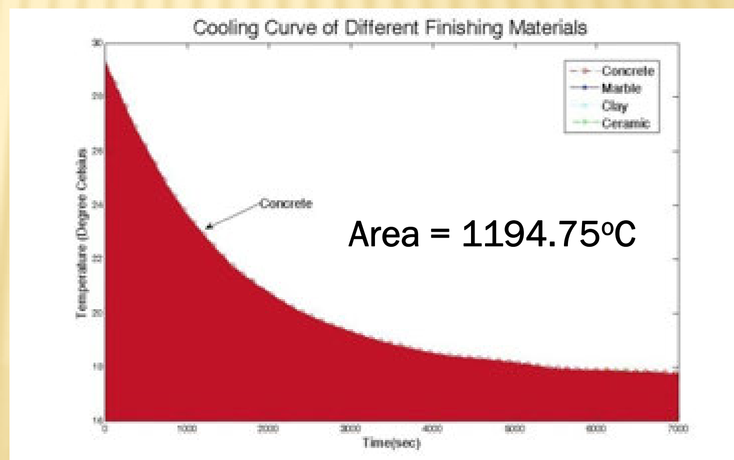
URBAN HEAT ISLAND EFFECT: TOTAL ENERGY RELEASED

- (2) Total energy released:









URBAN HEAT ISLAND EFFECT: SUMMARY

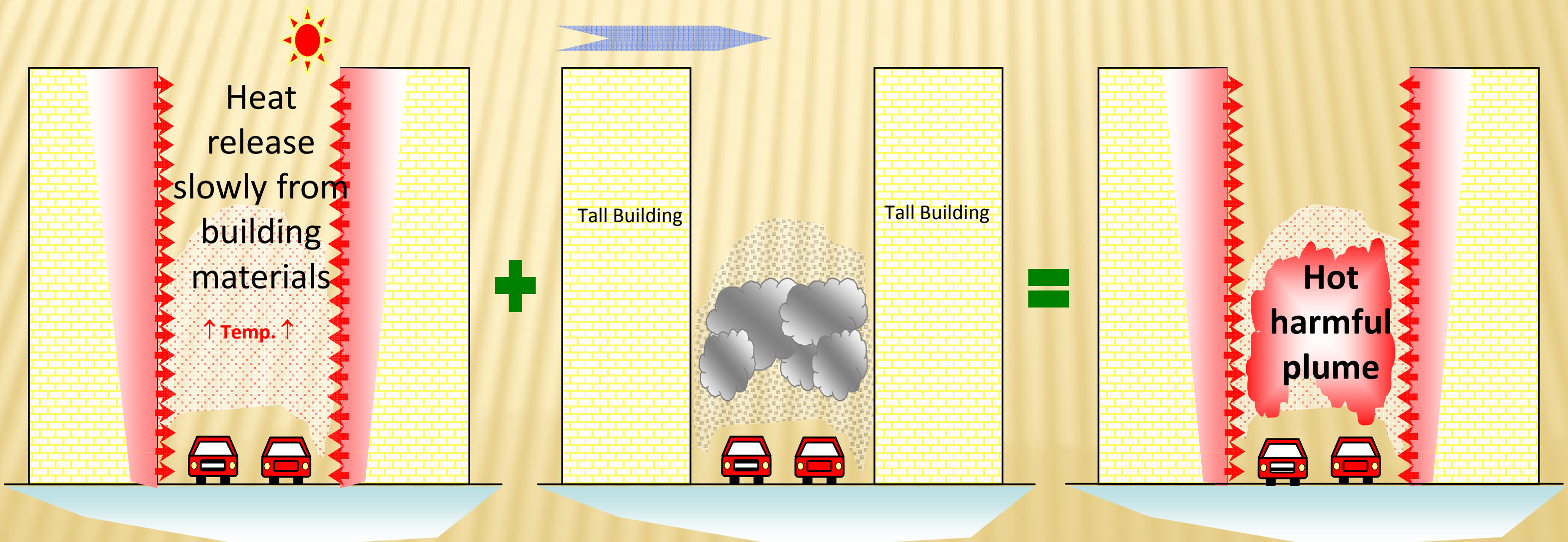
- Total energy released the four different building finishing materials:

	Concrete	Marble	Clay	Ceramic
Max. cooling rate	-0.0063	-0.0070	-0.0072	-0.0089 [ceramic cool fast]
Total energy	1194.75	1163.74	1130.97	1104.52

URBAN HEAT ISLAND EFFECT: ROLE OF BUILDING MATERIALS

	Concrete	Marble	Clay	Ceramic
Mean cooling rate of stage I	-0.0063	-0.0070	-0.0072	-0.0089 [ceramic cool fast]
Total energy	1194.75	1163.74	1130.97	1104.52

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



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

URBAN HEAT ISLAND EFFECT: ROLE OF BUILDING MATERIALS

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)

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Construction of Material Classification Index and UHI model

Extent of its potential contributions to the UHI

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Thank You !!