Ventilated facade design in hot and humid climate

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- **Background**
  - Principles
  - Case studies
- **Simulation**
  - Analysis
  - Results
- **Conclusions**
Background

• Need for sustainable development
• Key role of Building industry

Background

• Energy responsible approach

Energy consumption (Hong Kong)

- Building
- Industry
- Transport

Edited by Mat Haase, Image credit: http://www.emsd.gov.hk
Background

• Energy in buildings in HK

Energy consumption (Hong Kong)

- Commercial: 34%
- Transport: 36%
- Industry: 12%
- Residential: 18%
Background

- Energy in buildings in HK

Energy consumption in office buildings in HK

- Air-con 16%
- Lighting 11%
- Transport 11%
- Residential
- Industry
- Transport, Sanitary, others 7%

Energy consumption (Hong Kong)

27% of energy in HK is consumed by Air-con and Lighting in commercial buildings

Background

• Energy in buildings in HK

Energy in buildings in HK

- Lighting 32%
- Air-con 47%
- Transport, Sanitary, others 21%

27% of energy in HK is consumed by Air-con and Lighting in commercial buildings

Edited by Mat Haase, Image credits:
http://www.emsd.gov.hk and
http://arch.hku.hk/research/BEER/besc.htm
Background

- Possible integrated functions

- Façade technology
- Ventilation
- Sun protection/shadowing
- Photovoltaics
- Heating/cooling
- Passive solar
- Insulation
- Acoustic protection
- Daylight
Background

- New concepts for sustainable buildings
- Double-skin facades for office buildings

Left: Multimedia Center, Hamburg, Germany by Foster and Partners
Right: Uni, Erlangen, Germany by UBA Erlangen
Image credit: http://www.fosterandpartners.com
Background

Why double-skin façades?

Peak cooling load of office building in HK

- Window solar: 16.9%
- Window conduction: 6.9%
- Roof conduction: 0.2%
- Wall conduction: 12.0%
- Occupant (sensible): 14.5%
- Occupant (latent): 14.8%
- Artificial lighting: 19.6%
- Office equipment: 15.2%

Background

Why double-skin façades?

- Reduction of peak wind pressure
- Improvement of energy efficiency of façade by
  - passive solar heat gain in winter
  - reducing thermal losses in winter
  - reducing overall solar heat gain (in summer)
  - support of natural ventilation (with the stack effect)
Background

Why double-skin façades?

• Improving comfort
  ▪ **Thermal:** - predicted mean vote (PMV)
    - percentage people dissatisfied (PPD)
    - draft temperature
  ▪ **Visual:** - daylight factor
    - glare
    - view
  ▪ **Acoustic:** - intrusive noise

Image credits: Thermal comfort, INNOVA AirTec instruments and MatHaase
Background

Classification of double-skin façades (DSF)

Main Type
- Box window facade
- Corridor facade
- Shaft-box window facade
- Multi-storey facade

Cavity ventilation
- natural
- hybrid
- mechanical

Airflow concept
- Supply air
- Exhaust air
- Static air buffer
- External air curtain
- Internal air curtain

Haase, M., Amato, A., (2005), Double-skin facades for Hong Kong, proceedings of the Fifth International Postgraduate Research Conference in the Built and Human Environment, The University of Salford, UK.
Principles of DSF

Principles of airflow in cavity

open

not open

Exhaust air
Supply air
Static air buffer
External air curtain
Internal air curtain

Haase, M., Amato, A., (2005), Double-skin facades for Hong Kong, proceedings of the Fifth International Postgraduate Research Conference in the Built and Human Environment, The University of Salford, UK.
Background

Heat transfer

- **Radiation**
  - \( Q_{12} = \sigma A_1 \Phi_{12} (T_1^4 - T_2^4) \)

- **Conduction**
  - \( Q = \lambda A (T_1 - T_2) / t \)

- **Convection**
  - \( Q = h_c A \Delta T \)

- **Traditional performance criteria**
  - U-value, SHGC, meaningless

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**Diagram:**
- Primary facade
- Second glass layer
- Reflection
- Transmission
- Conduction and Convection
- Qin
- Qout
- \( N_1 \)
- \( N_2 \)
Background

Building design concept

Building energy consumption

Energy conservation

Increasing efficiency

Utilization of renewable energy resources

Haase, M. and Amato, A., (2005), Development of a double-skin facade system that combines airflow windows with solar chimneys, proceedings of Sustainable Building Conference (SB05), Poster session, Tokyo, Japan.
Background

Energy conservation

The diagram shows the energy conservation data from January to December. It includes the minimum and maximum temperature, heating degree hours, solar excess degree hours, and cooling degree hours. The data is represented in degrees Celsius and degree hours. The graph illustrates the temperature and degree hours trend throughout the year, highlighting the months with significant variations.
Climate analysis

Psychrometric Chart
Location: [NoName], [NoWhere]
Frequency: 1st January to 31st December
Weekday Times: 09:00-24:00 Hrs
Weekend Times: 09:00-24:00 Hrs
Barometric Pressure: 101.38 kPa
© A.J. Marsh '00

H-LITE: Climate Classification
Psychrometric Chart

Location: [NoName] [NoWhere]
Frequency: 1st January to 31st December
Weekday Times: 09:00-24:00 Hrs
Weekend Times: 09:00-24:00 Hrs
Barometric Pressure: 101.3 kPa
© A.J. Marsh '00

HLITE: Dry Bulb Air Temperature (°C)

Dry bulb temperature [°C]
Psychrometric Chart

Location: [NoName], [NoWhere]
Frequency: 1st January to 31st December
Weekday Times: 09:00-24:00 Hrs
Weekend Times: 09:00-24:00 Hrs
Barometric Pressure: 101.35 kPa
© A.J. Marsh '00

HLITE: Absolute Humidity Lines (g/kg)
Climate analysis

Psychrometric Chart
Location: [NoName], [NoWhere]
Frequency: 1st January to 31st December
Weekday Times: 00:00-24:00 Hrs
Weekend Times: 00:00-24:00 Hrs
Barometric Pressure: 101.36 kPa
© A.J. Marsh '00

HLITE: Relative Humidity Lines (%)
Climate analysis

Psychrometric Chart
Location: [NoName] [Nowhere]
Frequency: 1st January to 31st December
Weekday Times: 09:00-24:00 Hrs
Weekend Times: 09:00-24:00 Hrs
Barometric Pressure: 101.38 kPa
© A.J. Marsh '00

HLITE: Constant Enthalpy Lines (kJ/kg)

Dry bulb temperature [°C]

Abs. Humidity [AH]

Enthalpy [kJ/kg]

Psychrometric Chart

Climate analysis

Dry bulb temperature [°C]

Abs. Humidity [AH]

Enthalpy [kJ/kg]

Psychrometric Chart

Climate analysis

Dry bulb temperature [°C]

Abs. Humidity [AH]

Enthalpy [kJ/kg]
Psychrometric Chart

Location: Hong Kong, China
Frequency: 1st January to 31st December
Weekday Times: 00:00-24:00 Hrs
Weekend Times: 00:00-24:00 Hrs
Barometric Pressure: 101.36 kPa
© A.J. Marsh '00

Climate analysis

Psychrometric Chart

Location: Hong Kong, China
Frequency: 1st January to 31st December
Weekday Times: 00:00-24:00 Hrs
Weekend Times: 00:00-24:00 Hrs
Barometric Pressure: 101.36 kPa
© A.J. Marsh '00
Climate analysis

Selected energy conservation design strategies

1. exposed mass + night-purge ventilation
2. natural ventilation
3. direct evaporative cooling
4. indirect evaporative cooling
Climate analysis

Comfort Percentages
NAME: Hong Kong
LOCATION: China
WEEKDAYS: 08:00 - 20:00 Hrs
WEEKENDS: 08:00 - 13:00 Hrs
POSITION: 22.2°, 114.2°
© A.J. Marsh '00

- Passive Solar Heating
- Natural Ventilation
- Thermal Mass Effects
- Direct Evaporative Cooling
- Exposed Mass + Night-Purge Ventilation
- Indirect Evaporative Cooling
Case studies

Case studies of existing DSF in Hong Kong:

1. Dragon Air office building, Lantau
2. Kadoorie Biological Science Building, HKU
3. Science Park (Phase 1), Pak Shek Kok
4. Governmental offices, Shatin
5. No. 1 Peking Road, Kowloon
6. New emsd hq, Kai Tak
Case studies

• **Double-skin façade** (as in Dragon Air office and in Science Park)

• Double-skin cavity acts as external shading device

• Sealed façade with cavity externally naturally vented
Case studies

• Example of DSF with EAC: Dragon Air office building by Wong Tung & Ptns.

Image credit: www.dragonair.com and Meinhardt Facade Technology
Case studies

- Example of DSF with EAC:
- Science Park (Phase 1) by Simon Kwan
- Building here: with PV integrated
Case studies

- Example of DSF with EAC:
- Kadoorie Biological Science building by Leigh & Orange
- Building here: with HVAC system components in cavity
Case studies

- Airflow window
  (internal air curtain)

- Shatin Govermentnal Offices

- No. 1 Peking Road

- New emsd hq
Case studies

• Airflow window (internal air curtain)
  • Heat is concentrated in cavity
  • 10% exhaust air: savings in overall cooling energy possible
  • Improving thermal comfort
Case studies

- Example of AFW with IAC: Shatin Governmental Office by ASD
- Active window (developed by Meinhardt Façade Technology)

Image credits: HK Construction Ltd
Case studies

- Example of AFW with IAC: No. 1 Peking Road by Rocco Ltd
- Active façade system (developed by Permasteelisa Group)

Image credit: Permasteelisa and Mat Haase
Case studies

- Example of AFW with IAC: New emsd hq by ASD
- 2 upper storeys
- Refurbishment

Image credit: emsd and Mat Haase
Simulation

double-skin facades
base case
DSF
AFW
Simulation

double-skin facades

basecase

DSF

AFW

External glass layer

Internal movable blinds

AHU

External glass layer

Internal movable blinds

Spandrel panel

Internal glass layer
Simulation

- Thermal **building simulation coupled with airflow simulation**

<table>
<thead>
<tr>
<th>DSF</th>
<th>room</th>
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Simulation

- **Thermal building simulation coupled with airflow simulation**

- **DSF**
Simulation

- Thermal building simulation coupled with airflow simulation

- AFW
Cp over height

Façade 1

Façade 2

Façade 3

Façade 4

wind direction

0 45 90 135 180 225 270 315

DSF2-2 DSF2-3 DSF2-4
Results

Monthly results for simulation of DSF at different heights

- Simulation

- Results
Control strategies

- Controlling solar radiation
- Controlling HVAC
- Controlling exhaust airflow using a climate sensitive regulator
HVAC control

Air velocity AND temperature

Climate sensitive regulator

- Enthalpy balance

Haase, M. and Amato, A., (2005), Double-skin facades for Hong Kong, proceedings of the Fifth International Postgraduate Research Conference in the Built and Human Environment, The University of Salford, UK.
Simulation

• Results

Monthly simulation results for DSF and AFW with and without climate control.
• Results

Annual simulation results for DSF and AFW with and without climate control.
• Results

Simulation results for basecase, DSF and AFW
Conclusions

- Possible to design an energy efficient DSF system
- Amount of energy through the building envelope resulting in cooling loads can be reduced by designing a ventilated airflow window that is optimised in respect to heat transfer
- Airflow through the DSF depends on the cp-values of the façade, estimated the cp-values for different building shapes and heights did not influence the performance of the model with DSF
- The EAC uses buoyancy to reject solar heat gain
- Possibility to reduce annual cooling loads as well as peak cooling loads
- EAC with a climatic control better in reduction of cooling loads in the hot summer period
- IAC does not reduce cooling load
- Best results depend on an enthalpy based control that extracts air in order to reduce the cooling load
Conclusions

Planned future work

- Validation with measured data
- Detailed daylight analysis
- Solar assisted extract air device
- LCA of different façade systems
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http://thegreenroom.arch.hku.hk