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The Influence Of Thermochromic Glazing Parameters On Energy Saving And Comfort Criteria Using Moment-independent Measure

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Global Warming

Building sector

Act

Improve

Building envelope performance
(Pérez-Lombard and al., 2008)

Transparent surfaces
(Bülow-Hübe, 2001)
Context

Windows play an essential role in Architecture (Carmody et al., 2004)

Windows is important to provide:

- An exterior view
- Daylight

And also to:

- Thermal and phonic insulation
- Solar control
- Air quality control
- Security
Vanadium Dioxide: $\text{VO}_2$

- Thermochromic properties (Morin, 1959)
- Transition temperature: 68°C (Granqvist, 2016)
- Doping with other metals:
  - In Li and al., 2012:
    - Increase of the visible transmittance
    - Increase of the solar modulation
  - In Dietrich and al., 2015:
    - Decrease of the transition temperature

- In Saeli and al., 2010: (Cairo, Palermo, Roma)
  - ~30-40% of energy savings in comparison to a simple clear glazing

- In Liang and al., 2015: (London, Guangzhou)
  - Diminution of the cooling need
  - ~10-15% of energy savings in comparison to a double glazing
  - Decrease of glare occurrence

- In Costanzo and al., 2016: (Catania, Milan, Paris)
  - ~10% of discomfort time (Top>26°C) in comparison to a double glazing
  - ~25% of energy savings (max for hottest climate)
  - Decrease of glare occurrence and improvement of illuminance distribution

Thermochromic Glazing (TC)
Has the capability to modulate its thermo-optical properties dynamically and reversibly when a change in its temperature occurs.

Literature review

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Thermochromic Glazing (TC)

TC glazing for building application:

- Has to be doped with other metals to improve its properties
  - Transition temperature
  - Visible Transmittance
  - Solar modulation
- Has a potential to (Hoffmann et al., 2014)
  - Reduce energy consumption
  - Improve thermal and visual comfort
- Has a real efficiency for hot climates
Aim of the study

Identify the influence of thermochromic glazing parameters for hot climates using dynamic building simulations and sensitivity analysis techniques

- Thermal and daylighting simulations with EnergyPlus (DOE, 2010)
- Sensitivity analysis method with a Python code with the SAlib (Usher et al., 2016)
- Analysis on several indexes
- Study on 4 locations (hot tropical climates)

Tropical savanna climate (Kottek and al., 2006)
Methodology

Hypothesis: (office building)

- Dimensions: 6m x 5m x 3m
- Glazed surface exposed to solar radiation and wind
- Other surfaces are adiabatic
- No exterior obstructions
- Occupation: (Hoffmann et al., 2014)
  - 8am to 5pm
  - activity: 240 W (2 people)
- Electric equipment loads: 150 W/person
- Artificial lighting: 8 W/m²
  - If $E_{refs} < 300$ lux (CIE, 2002)
- Air conditioning:
  - $T_{set} = 24°C$
  - Flow rate: 20 m³/h per person

Simulations performed over an entire year
Methodology

Thermochromic glazing model in EnergyPlus (DOE, 2010)

\[ \tau \]

\[ \tau_{max} \]

\[ \tau_{min} \]

\[ \Delta \tau \]

\[ \Delta T_s \]

\[ T_s \]

\[ T (^\circ C) \]

Number of states = 5

Initialize \( T_{TC}^t \)

Find \( \tau^{t+1} \)

Solve heat balance and photometric model

\[ T_{TC}^{t+1} \]
## Sensitivity analysis

Moment-independent measure (Borgonovo, 2007)

\[ \delta_i = \frac{1}{2} E_{X_i} \left[ \int |f_Y(y) - f_Y|X_i(y)| \right] \]

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<th>UNIT</th>
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<td>Window to Wall Ratio</td>
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<td>5-99</td>
<td>%</td>
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<td>Insulation Thickness</td>
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<td>Weather File</td>
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<td>Switching Temperature</td>
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<td>Switching Temperature range</td>
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<td>Solar Transmittance Max</td>
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<td>Solar Transmittance range</td>
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<td>Visible Transmittance Max</td>
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<tr>
<td>Number of states</td>
<td>state</td>
<td>2-20</td>
<td>-</td>
<td>Discrete; Uniform</td>
</tr>
</tbody>
</table>

4096 simulations

Distribution and sampling of the parameters

Simulation of each parameters set

Analysis of Delta on the output
Model Outputs

Normalized output indexes

Energy consumption index
• Sum of the final energy consumed in one year
• Cooling and artificial lighting

Thermal comfort index (Costanzo and al., 2016)
• % of time when the temperature is below 26°C

Visual comfort index (David and al., 2011)
• % of time when the illuminance reference points are between 300 and 2000 lux
Results

Delta Moment measure analysis

- Window-to-Wall Ratio
- Orientation
- Solar transmittance max
- Weather File
- Solar transmittance range
- Switching temperature
- Visible transmittance max
- Number of states
- Visible transmittance range
- Switching temperature range
- Insulation thickness

Graphical representation showing various indices for different parameters.
Results

Distribution of input parameters

- Filtering model outputs according to a criteria
- Sorting given inputs by glazing size (small, medium, large)

Output distribution

Input distribution after filtering
Results

Distribution of input parameters

Energy consumption: [0; 0.40]

- WWR[5% - 35%]
- WWR[35% - 65%]
- WWR[65% - 99%]

Frequency

- $\tau_{sol, max}$
- $\Delta \tau_{sol}$
- $T_s [°C]$
Results

Distribution of input parameters

Visual comfort: [0.70; 1]

- WWR[5% - 35%]
- WWR[35% - 65%]
- WWR[65% - 99%]

Graphs showing frequency distribution for:
- $\tau_{vis, max}$
- $\Delta \tau_{vis}$
- $T_s [^\circ C]$
Limitations and drawbacks

• The TC glazing model used in EnergyPlus
  ▪ Step function: not representative of the real thermal behaviour (Mlyuka and al., 2009)

• The geometry and building configuration

• The input uniform probability
Conclusion

• Impact of several input variables on several model outputs
• Designers should pay attention to
  ▪ The glazing area size
  ▪ Building orientation
  ▪ Climate conditions
  ▪ Solar transmittance
  ▪ Visible transmittance
  ▪ Transition temperature
• TC glazing parameters values to obtain the best suitable scenario
• New data that lead to more accurate design strategies for low-energy office building in cooling-dominated climates
• Results could also serve as guidelines for the improvement of TC thin coating materials
Future works

• Study of the optimal parameters that reduce energy and improve comfort using optimization techniques

• Study of this method using passive cooling and natural ventilation for office buildings in hot tropical climates
  • Need to add new input, such as air flow rate and new output indexes
Thank you for your attention
Bibliography


Questions and discussions