Coupling Energy and Daylighting Simulation for Complex Fenestration Systems

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A task:

- DEVELOPMENT OF SHARED TRNSYS “DECK” TO INTEGRATE DIFFERENT BUILDING SUB-SYSTEMS SIMULATION “TYPES” (HVAC, ENVELOPE, DL, ...)
Motivation

enable DayLight simulation of CFS in Trnsys

Goal

- climate-based analysis/optimization of the building with respect to selected objectives
  - visual comfort
  - thermal comfort
  - energy
  - a combination of above
Motivation

enable DayLight simulation of CFS in Trnsys

Wishlist

- dynamic interaction between thermal and DL
- keep it accurate but flexible (custom controls design possible for energy/lighting optimization, codes/standard verification...)
- should not require a Radiance guru (reduced user effort in pre-processing)
Motivation

enable DayLight simulation of CFS in Trnsys

State of the art


Integrated Thermal and Light Simulations for Complex Daylight Systems Using TRNSYS and RADIANCE. Preliminary results from the project „Light From Façade“. 10th Intl. Radiance Workshop, August 24-26, 2011

➢ “artlight” dll with three-phase method implementation was developed. Not published...
Main output of this work

“Type_DLT.dll” for Trnsys:

✓ C++ coded
✓ Three Phase Daylight Coefficient Method
✓ Open source
Tool-chain 1/2

pre-processing

Window 6.3

Google SketchUp

A text editor

- BSDF (or from genBSDF)
  - glazing parameters

- geometry
- physical properties

- config. files with basic Radiance param. (view, windows, glow)

Input data

yet not 100% automatic...
Tool-chain 2/2

Input data → Trnsys 17 (each simulation step: run Radiance through the Type_DLT) → Output data

Annual building simulation
Manual configuration files

**CFS1.rad**

```plaintext
void glow CFS1
0
0
4 1 1 1 0
CFS1 polygon f_16_0
0
4 1 1 1 0
CFS1 polygon f_16_0
0
12
-23.095208  130.979431
4.100000
-23.095208  130.979431
10.400000
-0.173648  0.984808
10.400000
-0.173648  0.984808
4.100000
```

**window group list file:**
*window modifier + view direction + view up*

**win.dat**

```plaintext
1 # number of windows groups
CFS1 0.984807729721 0.173648163676 0 0 0 1
```

windows geometry (one file per each windows group)
Simulation tests. Two control approaches

Assumptions

- variable geometry shading (e.g. venetian blinds angles)
- dimming lights

Tested approaches to control design:
1. optimal daylighting approach: “DLT”
2. optimal energy approach: “Th”
Simulation tests. Two control approaches

**DLT approach**

maximise visible light transmission while keeping visual comfort

**inputs**

- current shading state
- computed average illuminance on working planes
- maximum illuminance (comfort target)

**output**

optimal shading state
Simulation tests. Two control approaches

Th approach

maximise thermal comfort optimizing solar gains

inputs

Winter

- current shading state
- target comfort temperature

Summer

- current shading state
- total radiation on façade

output

optimal shading state
Simulation approach: Th. Variable shading

EACH SIM STEP

Control variable (t-1) → Control algorithm → Shading state (t) → Type_DLT → Visual comfort index

Change the state (open/closed)

THERMAL FEEDBACK CONTROL

Thermal simulation (Type56) → Light dimming

Control variable (t) → computed or from weather file
Simulation approach **DLT. Variable shading**

**INTERNAL LOOP PER EACH SIM STEP**

1. **Shading state** $(k-1)$
2. **Visual comfort target**
3. **Control algorithm**
4. **Shading state** $(k)$
5. **Visual comfort index**

**DAYLIGHT FEEDBACK CONTROL**

- Change the state (slat angle) until the closest index $\leq$ target is reached

- **Optimized shading state**
- **Light dimming**
- **Thermal simulation (Type56)**
Thermal model of the CFS

• In this work:
  • Shading factor computed from SHGC (still not angle dependent):

\[ F_c = \frac{(\text{SHGC(clear\_glass)} - \text{SHGC(CFS)})}{\text{SHGC(clear\_glass)}} \]

• Next step: implementation of ISO 15099 detailed calculation (uses BSDF)
Trnsys deck implementation. Th
Trnsys deck implementation. DLT
The demo test

Shopping mall area. Large supermarket

<table>
<thead>
<tr>
<th>Reflection factor</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal wall</td>
<td>0.5</td>
</tr>
<tr>
<td>Ceiling</td>
<td>0.8</td>
</tr>
<tr>
<td>Floor</td>
<td>0.2</td>
</tr>
<tr>
<td>External wall, ground</td>
<td>0.35</td>
</tr>
</tbody>
</table>
The demo test

Sensor grid. 11 sensors on a row on cash registers
**The demo test**

Solar control glazing (double pane)

### Glazing System Library

- **ID #**: 1
- **Name**: clearglass_solar_control
- **Layers**: 2
- **Tilt**: 90°
- **IG Height**: 1000.00 mm
- **IG Width**: 1000.00 mm
- **Environmental Conditions**: NFRC 100-2010
- **Overall thickness**: 20.000 mm
- **Mode**: 

<table>
<thead>
<tr>
<th>ID</th>
<th>Name</th>
<th>Mode</th>
<th>Thick</th>
<th>Flip</th>
<th>Tsol</th>
<th>Rsol1</th>
<th>Rsol2</th>
<th>Tvis</th>
<th>Rvis1</th>
<th>Rvis2</th>
<th>Tir</th>
<th>E1</th>
<th>E2</th>
<th>Cond</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Glass 1</td>
<td>#</td>
<td>4.0</td>
<td>☒</td>
<td>0.588</td>
<td>0.246</td>
<td>0.312</td>
<td>0.889</td>
<td>0.055</td>
<td>0.048</td>
<td>0.000</td>
<td>0.837</td>
<td>0.037</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Gap 1</td>
<td>2</td>
<td>12.0</td>
<td>☒</td>
<td>0.842</td>
<td>0.076</td>
<td>0.076</td>
<td>0.900</td>
<td>0.082</td>
<td>0.082</td>
<td>0.000</td>
<td>0.837</td>
<td>0.837</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Glass 2</td>
<td>#</td>
<td>4.0</td>
<td>☒</td>
<td>0.810</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Center of Glass Results

<table>
<thead>
<tr>
<th>Ufactor</th>
<th>SC</th>
<th>SHGC</th>
<th>Rel. Ht. Gain</th>
<th>Tvis</th>
<th>Keff</th>
<th>Gap 1 Keff</th>
</tr>
</thead>
<tbody>
<tr>
<td>W/m²K</td>
<td></td>
<td></td>
<td>W/m²</td>
<td>W/m²K</td>
<td>W/m-K</td>
<td>W/m-K</td>
</tr>
<tr>
<td>1.360</td>
<td>0.653</td>
<td>0.568</td>
<td>422</td>
<td>0.810</td>
<td>0.0218</td>
<td>0.0218</td>
</tr>
</tbody>
</table>
The demo test

Exterior venetian blinds (variable tilt angle)
Simulation baseline

- Time step: 1h
- Simulation period: 1 year
- Climate data source: Meteonorm
- Winter period: 15th October – 15th April
- Temperature setpoint: Tmin = 17 °C; Tmax = 24 °C (all seasons)
- Target comfort temperature: 23 °C (winter)
- Visual comfort target range: 300 – 2000 lux
- Total radiation on façade: 55 W/sqm (summer)
- Internal loads:
  - electric lights
  - 1000 people
  - cooling devices (food)
  - thermal losses through: main transparent façade, floor, ceiling, back wall
- Dimming parameters: from A. Mc Neil, *Tutorial on three-phase method for complex fenestration system*
Simulation baseline

- Comparison of DLT and Th control approaches

- **DLT control. 5-position tilted slats**

<table>
<thead>
<tr>
<th>State</th>
<th>Shading state</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>clear glass</td>
</tr>
<tr>
<td>1</td>
<td>tilt angle 15°</td>
</tr>
<tr>
<td>2</td>
<td>tilt angle 30°</td>
</tr>
<tr>
<td>3</td>
<td>tilt angle 45°</td>
</tr>
<tr>
<td>4</td>
<td>tilt angle 60°</td>
</tr>
</tbody>
</table>

- **Th control. 2-state shading**

<table>
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<th>Shading state</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>clear glass</td>
</tr>
<tr>
<td>1</td>
<td>tilt angle 60°</td>
</tr>
</tbody>
</table>
Results

Illuminance

Illuminance [lux]

Time [day]

Th Control - DLT Control - 2000 lux

FP7 European Union Funding for Research & Innovation
Results

Illuminance (log scale)

Illuminance [lux]

Time [day]

Th Control  DLT Control  2000 lux
Illuminance - 17\textsuperscript{th} June

![Graph showing illuminance data over time with Th Control and DLT Control lines.]

Shading Control - 17\textsuperscript{th} June

![Bar chart showing shading state over time with Th Control and DLT Control categories.]

regime: summer
Shading state

Illuminance - 4th October

Time [hour]

DLT Control
Th Control

Shading Control - 4th October

Illuminance [lux]

0 200 400 600 800 1000 1200 1400 1600 1800

7 9 11 13 15 17 19

0 1 2 3 4

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23

Time [hour]

DLT Control
Th Control

regime: summer
regime: winter

Illuminance - 17th January

Shading Control - 17th January

FP7 European Union Funding for Research & Innovation

Time [hour]

Illuminance [lux]

Shading state

Th Control

DLT Control
## Results

Comparison of annual energy consumption

<table>
<thead>
<tr>
<th></th>
<th>Heating demand (kWh)</th>
<th>Cooling demand (kWh)</th>
<th>Total power demand (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TH Control</td>
<td>1385.8</td>
<td>539061.8</td>
<td>540447.6</td>
</tr>
<tr>
<td>DLT Control</td>
<td>3315.4</td>
<td>572007.3</td>
<td>575322.7</td>
</tr>
<tr>
<td><strong>Difference [GWh]</strong></td>
<td><strong>-34.875</strong></td>
<td></td>
<td><strong>-6%</strong></td>
</tr>
</tbody>
</table>
Conclusions

“type_DLT.dll” enable daylighting simulation and control design in Trnsys:

- Preliminary tests consistent
- Actual façade to be implemented
- Multi-objective optimization algorithms to be explored
- Source code and examples to be published
THANK YOU!

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