Hygrothermal Performance of Cool Reflective and Conventional Roofs

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On Behalf of

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OUTLINE

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- Environmental Conditions
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Introduction

**hygrothermal IRC-COMSOL** → **hygIRC-C**

- recently developed
- solves 2D and 3D time dependent HAM transport equations.
- benchmarked against existing hygIRC-2D and experiments

**New features:**
- CFD capability to model drainage cavities, airspaces, cracks, etc… as well as aerodynamics on buildings
- Heat transfer by radiation through airspace enclosures of building envelope (e.g. reflective insulations)
- Runoff due to wind driven rain on facades
• Examples of Numerical Simulations Conducted Using 2D and 3D hygIRC-C:
  1. hygIRC-C vs hygIRC
  2. Wetting and Drying of Cladding Systems
  3. Moisture Assessment of Cladding Systems
  4. Drying of Ventilated Wall Cavities
  5. Evaluating Wall Energy Rating (WER)
  7. Foundation Wall Systems with Furred-Airspace Assembly
  8. Insulated Concrete Foam (ICF) Wall systems
  9. **Hygrothermal Performance of Roofing Systems**
  10. Aerodynamics on Buildings
  11. Thermal Performance of EIFS Walls with Drainage Cavities
  12. Hygrothermal Performance of Samples Used in Current Mould Experiments
  13. Phase Change Materials (PCMs)
A new module for predicting the risk for mould growth will be implemented in hygIRC-C.

hygIRC-C will be used to predict the performance of the whole building.
Introduction (cont.)

2D & 3D hygIRF-C Modules

- Hygrothermal Modeling
- CFD

Done

On going…
(IE-BES cross-program)

- Mould Risk Assessment

✓ Hygrothermal Modeling
✓ CFD
Objectives

- Use hygIRC-C to investigate the hygrothermal performance of reflective and non-reflective roof systems subjected to North American climates.
- Investigate the effect of indoor conditions on the roof performance.
- Compare the hygrothermal performance (moisture and energy loss/gain) of reflective and non-reflective roof systems.
Roof System Configurations

MOD-BIT

Steel Deck (From Canam)

P-3615 & P-3606 → P-3615
Cap Sheet with Base Sheet

0.30” → 7.34 mm total thickness
92 PERD Torch applied asphalt based membrane

1” Fibreboard
54 ASHRAE Fibreboard

Insulation:
Polyisocyanurate → 2” (50 mm)
72 ASHRAE Polyisocyanurate Insulation

Steel Deck (P-3615)

Steel deck vapor permeance
3.3 m (5 US perms)
Hygrothermal Modeling

**Assumptions:**
All material layers are in good contact

**Initial Conditions:**
- Moisture Content in all layers corresponding to 50% RH and $T = 10^\circ$C

**Indoor Conditions:**
- ASHRAE
- EN15026

**Outdoor Conditions:**
Weather data of North America
- NRC weather database

**Time for simulation:**
- 5 years
- Up to 11 years

**Solar short-wave absorption coeff.:**
- 0.2 (white roof)
- 0.88 (black roof)

**Long-wave emissivity:**
- 0.9 for black & white roofs

**Material Properties:**
- NRC material database
Environmental Conditions

Outdoor Conditions: North American Climates

Canadian cities (NBCC):
- ✓ Toronto (HDD = 3650)
- ✓ Montreal (HHD = 4200)
- ✓ St. John’s (HDD = 4800)
- ✓ Saskatoon (HDD = 5950)

US cities:
- ✓ Seattle (HDD = 2564)
- ✓ Wilmington (HDD = 1349)
- ✓ Phoenix (HDD = 578)
Environmental Conditions (cont.)

Indoor Conditions: ASHRAE vs EN15026

Time = 0 → Jan 1

Environmental Conditions (cont.)

Indoor Conditions: ASHRAE vs EN15026

Time = 0 → Jan 1
Environmental Conditions (cont.)

Indoor Conditions: ASHRAE vs EN15026

Time = 0 → Jan 1st
ASHRAE vs EN15026

Results (cont.)

RH_{avg} in FB (%)

White (ASHRAE)
White (EN 15026)
Black (EN 15026)
Black (ASHRAE)

Time = 0 \rightarrow Jan 1^{st}
ASHRAE vs EN15026

Results (cont.)

**Time = 0 → Jan 1st**
Toronto, EN15026 (black roof)

Temperature contours (in °C)

(a) time = 4356 h (July 1st at noon)

(b) time = 8760 h (end of the year)
Toronto, EN15026 (black roof)

Results (cont.)

(a) Temperature (°C) (July 1st at noon)
(b) RH (%) (July 1st at noon)
(c) Vertical velocity (mm/s) (July 1st at noon)

(d) Temperature (°C) (at end of the year)
(e) RH (%) (at end of the year)
(f) Vertical velocity (mm/s) (at end of the year)

\[ T_{\text{outdoor}} > T_{\text{indoor}} \]

\[ T_{\text{outdoor}} < T_{\text{indoor}} \]
Results (cont.)

Average External Surface Temperature (°C)

Time (day)

Toronto, EN15026
Toronto, EN15026

Results (cont.)

Heat rate for 76 mm length per m width (W/m)

Heat loss

Heat gain

Time (day)
### Results (cont.)

**Average External Surface Temperature (°C)**

<table>
<thead>
<tr>
<th></th>
<th>JAN</th>
<th>FEB</th>
<th>MAR</th>
<th>APR</th>
<th>MAY</th>
<th>JUN</th>
<th>JUL</th>
<th>AUG</th>
<th>SEP</th>
<th>OCT</th>
<th>NOV</th>
<th>DEC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>White</strong></td>
<td>-3.2</td>
<td>-5.3</td>
<td>4.5</td>
<td>8.2</td>
<td>12.7</td>
<td>20.7</td>
<td>23.0</td>
<td>23.4</td>
<td>16.8</td>
<td>11.6</td>
<td>4.0</td>
<td>-3.3</td>
</tr>
<tr>
<td><strong>Black</strong></td>
<td>-1.9</td>
<td>-2.5</td>
<td>7.3</td>
<td>12.1</td>
<td>17.0</td>
<td>26.6</td>
<td>29.0</td>
<td>28.9</td>
<td>21.4</td>
<td>14.3</td>
<td>5.1</td>
<td>-1.9</td>
</tr>
</tbody>
</table>

The diagram shows the average external surface temperature in Toronto, EN15026, for different months and colors, with blue and red bars representing different conditions.
Toronto, EN15026

Heat rate for 76 mm length per m width (W/m)

+ve: System may contribute to cooling load
-ve: System may contribute to heating load

<table>
<thead>
<tr>
<th></th>
<th>JAN</th>
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<th>MAY</th>
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<th>SEP</th>
<th>OCT</th>
<th>NOV</th>
<th>DEC</th>
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</thead>
<tbody>
<tr>
<td>White</td>
<td>-0.67</td>
<td>-0.73</td>
<td>-0.45</td>
<td>-0.36</td>
<td>-0.25</td>
<td>-0.09</td>
<td>-0.04</td>
<td>-0.03</td>
<td>-0.16</td>
<td>-0.27</td>
<td>-0.46</td>
<td>-0.67</td>
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<tr>
<td>Black</td>
<td>-0.63</td>
<td>-0.65</td>
<td>-0.37</td>
<td>-0.25</td>
<td>-0.12</td>
<td>0.08</td>
<td>0.14</td>
<td>0.13</td>
<td>-0.03</td>
<td>-0.20</td>
<td>-0.43</td>
<td>-0.63</td>
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</tbody>
</table>
EN15026

Results (cont.)

(a) Montreal

(b) St John’s

(c) Saskatoon

(d) Seattle

(e) Wilmington

(f) Phoenix
<table>
<thead>
<tr>
<th>City</th>
<th>Maximum Surface Temperature (°C)</th>
<th>Minimum Surface Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hourly</td>
<td>Monthly Average</td>
</tr>
<tr>
<td></td>
<td>Black Roof</td>
<td>White Roof</td>
</tr>
<tr>
<td>Toronto</td>
<td>67</td>
<td>39</td>
</tr>
<tr>
<td>Montreal</td>
<td>75</td>
<td>39</td>
</tr>
<tr>
<td>St John's</td>
<td>51</td>
<td>32</td>
</tr>
<tr>
<td>Saskatoon</td>
<td>65</td>
<td>39</td>
</tr>
<tr>
<td>Seattle</td>
<td>68</td>
<td>39</td>
</tr>
<tr>
<td>Wilmington</td>
<td>78</td>
<td>42</td>
</tr>
<tr>
<td>Phoenix</td>
<td>81</td>
<td>52</td>
</tr>
</tbody>
</table>

Note: The table above shows the maximum and minimum surface temperatures for different cities with black and white roofs. The temperatures are given in hourly and monthly average values.
Results (cont.)

Heat rate for 76 mm length per m width (W/m)

**Montreal**

- **Positive (White):** System may contribute to cooling load
- **Negative (Black):** System may contribute to heating load

**St John’s**

- **Positive (White):** System may contribute to cooling load
- **Negative (Black):** System may contribute to heating load

**Saskatoon**

- **Positive (White):** System may contribute to cooling load
- **Negative (Black):** System may contribute to heating load

**Seattle**

- **Positive (White):** System may contribute to cooling load
- **Negative (Black):** System may contribute to heating load

**Wilmington**

- **Positive (White):** System may contribute to cooling load
- **Negative (Black):** System may contribute to heating load

**Phoenix**

- **Positive (White):** System may contribute to cooling load
- **Negative (Black):** System may contribute to heating load
<table>
<thead>
<tr>
<th>City</th>
<th>Yearly Accumulation</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Energy Gain (Wd/m)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Black Roof</td>
<td>White Roof</td>
</tr>
<tr>
<td>Toronto</td>
<td>26.2</td>
<td>4.9</td>
</tr>
<tr>
<td>Montreal</td>
<td>25.7</td>
<td>3.8</td>
</tr>
<tr>
<td>St John's</td>
<td>6.8</td>
<td>0.5</td>
</tr>
<tr>
<td>Saskatoon</td>
<td>15.4</td>
<td>2.1</td>
</tr>
<tr>
<td>Seattle</td>
<td>30.7</td>
<td>4.5</td>
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<tr>
<td>Wilmington</td>
<td>61.8</td>
<td>14.9</td>
</tr>
<tr>
<td>Phoenix</td>
<td>126.5</td>
<td>53.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>City</th>
<th>Yearly Accumulation</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Energy Loss (Wd/m)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Black Roof</td>
<td>White Roof</td>
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<tr>
<td>Toronto</td>
<td>-116.1</td>
<td>-131.9</td>
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<tr>
<td>Montreal</td>
<td>-131.0</td>
<td>-151.3</td>
</tr>
<tr>
<td>St John's</td>
<td>-146.3</td>
<td>-162.8</td>
</tr>
<tr>
<td>Saskatoon</td>
<td>-168.1</td>
<td>-188.1</td>
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<tr>
<td>Seattle</td>
<td>-82.2</td>
<td>-98.5</td>
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<tr>
<td>Wilmington</td>
<td>-44.4</td>
<td>-55.9</td>
</tr>
<tr>
<td>Phoenix</td>
<td>-25.7</td>
<td>-33.4</td>
</tr>
</tbody>
</table>

**Cooling Load**

**Heating Load**

*Cooling Load* and *Heating Load* are calculated based on the yearly accumulation of energy gain and loss, respectively. The ratios indicate the comparison between Black and White roofs, with the percentage of cooling or heating load given in the last column.
Results (cont.)

Black Roof, EN15026

MC\text{avg} \text{ in FB} (\text{kg}_w/\text{kg}_{dm} \%)

Time = 0 \rightarrow \text{Jan 1}^{\text{st}}
Results (cont.)

Maximum $MC_{avg}$ in FB (kg$_{w}$/kg$_{dm}$ %)

- Phoenix
- Wilmington
- Seattle
- Montreal
- Toronto
- St John's
- Saskatoon

Time = 0 → Jan 1$^{st}$
Results (cont.)

White Roof, EN15026

Time = 0 → Jan 1st
White Roof, EN15026

Results (cont.)

Time = 0 → Jan 1st
Results (cont.)

Black Roof, EN15026

Time = 0 → Jan 1st

MC of the Upper Surface of FB (kg\textsubscript{w}/kg\textsubscript{dm} %)

- Phoenix
- Wilmington
- Seattle
- Montreal
- Toronto
- St John's
- Saskatoon

19% MC

Black Roof

Time (day)

MC of the Upper Surface of FB (kg\textsubscript{w}/kg\textsubscript{dm} %)
Results (cont.)

MC of the Upper Surface of FB (kg\(w\)/kg\(dm\) %)

- Phoenix
- Wilmington
- Seattle
- Montreal
- Toronto
- St John's
- Saskatoon

Time = 0 → Jan 1\(^{st}\)

19% MC
Summary

- hygIRC-C was used to predict the hygrothermal performance of white and black MOD-BIT roofs subjected to different climates of North America
- The EN15026 indoor condition resulted in higher Moisture Content (MC) in the roof compared to ASHRAE indoor condition
- White roofs require less cooling load in summer compared to black roofs
- White roofs require more heating load in winter compared to black roofs
- White roofs run with low risk of moisture accumulation in all cities investigated in this paper except in St. John’s and Saskatoon