Experimental and numerical investigations to compare the thermal performance of infrared reflecting insulation and mineral wool

Matthias Kersken, Almuth Schade

9th Nordic Symposium on Building Physics, Tampere, 29 May – 2 June 2011
Insulation Materials

**Mineral Wool (MW)**

![Mineral Wool Image]

\[ R = 5.7 \text{ m}^2\text{K/W} \]

**Infrared - Reflective Insulation (RI)**

![Reflective Insulation Image]

\[ R^* = 5.7 \text{ m}^2\text{K/W} \]

thermal resistance
mineral wool

=  
thermal resistance
IR reflective insulation

?
Experimental Buildings

view from south west
Mineral Wool Roof System 1

1. Roofing Tiles
2. Lathing / Air Space
3. Counter Lathing / Air Space
4. Under Tile Liner
5. Rafter 195/95
6. Mineral Wool 035 40 mm
7. Mineral Wool 035 160 mm
8. Vapour Retarder
9. Lathing / Air Space
10. Plasterboard
Mineral Wool Roof System 2

1. Roofing Tiles
2. Lathing / Air Space
3. Counter Lathing / Air Space
4. Under Tile Liner
5. Rafter 195/95 Ventilated Air Space
6. Mineral Wool 040 200mm
7. Anchor Bar
8. Aluminium Profile
9. Plasterboard
Mineral Wool Roof System 3

1. Roofsing Tiles
2. Lathing / Air Space
3. Counter Lathing / Air Space
4. Under Tile Liner
5. Ventilated Air Space 15 mm
6. Rafter 95/195
7. Mineral Wool 035 180 mm
8. Vapour Retarder
9. Aluminium Profile
10. Plasterboard
Different IR-reflective Insulation Roof Systems

RI 1

1. Roofing Tiles
2. Lathing / Air Space
3. Counter Lathing / Air Space
4. Under Tile Liner
5. Rafter 95/195
6. IR-reflecting Insulation
7. Lathing / Air Space
8. Plasterboard

RI 2

1. Roofing Tiles
2. Lathing / Air Space
3. Counter Lathing / Air Space
4. IR-reflecting Insulation
5. Rafter 95/195
6. Lathing / Air Space
7. Plasterboard
Measurement System

1. SÜD
2. 3 4 5 6
3. NORD

IR-reflective insulation attic

mineral wool attic

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Examination Winter 2007 / 2008

3 measurement periods comparing different roof systems

RI 1

MW 1

MW 2

MW 3
1. $n_{50} < 1 \, h^{-1}$  high air tightness

2. $n_{50} \approx 3 \, h^{-1}$  design limit acc. EnEV (german energy saving regulations) for natural ventilated buildings

3. $n_{50} \approx 10 \, h^{-1}$  not air tight
Winter Investigations

heating demand = transmission heat losses + infiltration heat losses (through all envelopes incl. roof)

G R O U N D F L O O R  A T T I C

heater heater
Energy Balance (winter): heat sources
Energy Balance (winter): heat losses

- heat loss through the roof:
  - energy consumption (radiators)
  - transmission heat losses of envelopes (other than roof)
  - infiltration heat losses
### Energy balance winter 2007 / 2008

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Climatic boundary conditions (mean values)</td>
<td>External temperature</td>
<td>-2.0 °C</td>
<td>-4.9 °C</td>
<td>-5.4 °C</td>
</tr>
<tr>
<td></td>
<td>Global radiation</td>
<td>46 W/m²</td>
<td>108 W/m²</td>
<td>162 W/m²</td>
</tr>
<tr>
<td></td>
<td>Wind speed</td>
<td>2.1 m/s</td>
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<tr>
<td>Heat losses envelope areas besides the roof (calculated by measured heat flows)</td>
<td>MW 1</td>
<td>172 kWh</td>
<td>184 kWh</td>
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<td>RI 1</td>
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<td>Infiltration heat losses (acc. EN 832 [2] determined by tracer gas measurement)</td>
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<td>Energy consumption (measured)</td>
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<td>806 kWh</td>
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<td>100 %</td>
<td>205 %</td>
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<td>Heat losses through the roof (determined by energy balance)</td>
<td>281 kWh</td>
<td>251 %</td>
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© Fraunhofer IBP
**Energy balance winter 2007 / 2008**

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# Energy balance winter 2008 / 2009

## Winter 2008/2009

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<th>Energy balance of the 3 measurement periods</th>
<th>$n_{50} \approx 0.7 \text{ h}^{-1}$</th>
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<td>36 days – 864 h</td>
<td>44 days – 1056 h</td>
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### Climatic boundary conditions (mean values)

- **External temperature**
  - $-2.2 \, ^\circ\text{C}$
  - $-1.0 \, ^\circ\text{C}$
  - $-8.6 \, ^\circ\text{C}$

- **Global radiation**
  - $44 \, \text{W/m}^2$
  - $84 \, \text{W/m}^2$
  - $199 \, \text{W/m}^2$

- **Wind speed**
  - $2.1 \, \text{m/s}$
  - $3.6 \, \text{m/s}$
  - $2.8 \, \text{m/s}$

### Heat losses envelope areas besides the roof (calculated by measured heat flows)

- MW 3: 200 kWh
- RI 2: 205 kWh
- MW 3: 160 kWh
- RI 2: 138 kWh
- MW 3: 82 kWh
- RI 2: 70 kWh

### Infiltration heat losses (acc. EN 832 [2] determined by tracer gas measurement)

- MW 3: 116 kWh
- RI 2: 128 kWh
- MW 3: 174 kWh
- RI 2: 146 kWh

Large fluctuations due to very low air tightness.

### Energy consumption (measured)

- MW 3: 790 kWh
- RI 2: 1787 kWh
- MW 3: 642 kWh
- RI 2: 1336 kWh
- MW 3: 426 kWh
- RI 2: 852 kWh

- 100 %
- 226 %
- 100 %
- 208 %
- 100 %
- 200 %

### Heat losses through the roof (determined by energy balance respectively for $n_{50} \approx 10 \text{ h}^{-1}$ determined by measured heat flow)

- MW 3: 474 kWh
- RI 2: 1454 kWh
- MW 3: 308 kWh
- RI 2: 1052 kWh
- MW 3: 205 kWh
- RI 2: 687 kWh

- 100 %
- 307 %
- 100 %
- 342 %
- 100 %
- 335 %
# Energy balance winter 2008 / 2009

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<td>-8.6 °C 199 W/m² 2.8 m/s</td>
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<td>Heat losses envelope areas besides the roof (calculated by measured heat flows)</td>
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<td>Energy consumption (measured)</td>
<td>790 kWh 1787 kWh</td>
<td>642 kWh 1336 kWh</td>
<td>426 kWh 852 kWh</td>
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<td>Heat losses through the roof (determined by energy balance respectively for $n_{50} \approx 10 \text{ h}^{-1}$ determined by measured heat flow)</td>
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Thermal Resistance (R-Value)

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<tr>
<th>Material</th>
<th>Mineral Wool MW</th>
<th>Infrared Reflecting Insulation RI</th>
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<tr>
<td>Thermal Resistance R [m²K/W]</td>
<td>5.69</td>
<td>1.00</td>
</tr>
<tr>
<td>Method</td>
<td>Hot plate method installation: horizontal</td>
<td>Hotbox method installation: vertical</td>
</tr>
<tr>
<td>Emissivity [-]</td>
<td>Not determined</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Laboratory Values

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<thead>
<tr>
<th>Roof System</th>
<th>Mineral Wool MW</th>
<th>IR-Reflecting Insulation RI</th>
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<tbody>
<tr>
<td>Thermal Resistance R [m²K/W]</td>
<td>Acc. ISO 6946</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Using laboratory values</td>
<td>6.0</td>
</tr>
<tr>
<td></td>
<td>2.1</td>
<td>2.1</td>
</tr>
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Thermal Resistance (R-Value)

weather conditions
11 to 12 December 2007
## Thermal Resistance (R-Value)

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<tr>
<th>Material</th>
<th>Insulation Type</th>
<th>Thermal Resistance $R$ [m$^2$K/W]</th>
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<td>mineral wool MW</td>
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<td>roof system</td>
<td></td>
<td>acc. ISO 6946 using laboratory values</td>
</tr>
<tr>
<td>thermal resistance $R$</td>
<td></td>
<td>R [$m^2K/W$]</td>
</tr>
<tr>
<td>in-situ thermal resistance $R_{insitu}$</td>
<td>determined by measurement data</td>
<td>6.4 2.0</td>
</tr>
</tbody>
</table>
Summer tests varying the following parameters:
- with or without cooling
- with or without ventilation
- simulated window
- internal heat gains
investigation with internal heat gains, without cooling or ventilation:
evaluation by means of the total energy consumption is not reasonable

→ dynamic calculations
Dynamic Calculations: Validation

<table>
<thead>
<tr>
<th>measurement period</th>
<th>winter 1</th>
<th>winter 2</th>
<th>summer 1</th>
<th>summer 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>days [d]</td>
<td>39</td>
<td>29</td>
<td>10</td>
<td>5</td>
</tr>
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</table>
Dynamic Calculations: Validation

<table>
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<tr>
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<tbody>
<tr>
<td>days [d]</td>
<td>39</td>
<td>29</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>parameter for comparison of measurement and simulation</td>
<td>heat consumption</td>
<td>room temperature</td>
<td></td>
<td></td>
</tr>
<tr>
<td>difference MW attic [%]</td>
<td>8.4</td>
<td>5.9</td>
<td>room temperature simulation in the range of all 5 measured values of room temperature (1)</td>
<td></td>
</tr>
<tr>
<td>difference RI attic [%]</td>
<td>1.9</td>
<td>4.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Graphs showing measured and simulated temperatures for MW and RI attics.](image)
Dynamic Calculations: different boundary conditions

- climate data of different places
- infiltration
- internal heat gains
- orientation
- fenestration
- ventilation
- cooling
Summary and conclusions

- heat losses through the RI-roof are more than twice as much than through the MW-roof

- high radiation reduces the energy consumption more in the RI-attic than in the MW-attic
  
  → the thermal resistance of examined IR-reflective insulation is much lower than the thermal resistance of 18 to 20 cm mineral wool

- reducing the air tightness of both attics to the same, lower level does not change the ratio of energy consumption between both attics considerably during a whole measurement period
Summary and conclusions

- high wind impact may decrease the thermal resistance of mineral wool
  → air tight installation of mineral wool to avoid air flow through insulation is recommended

- in situ measurement is influenced by prevailing weather conditions and other boundary conditions
  → thermal parameters should not be determined by in situ testing only

- in situ thermal resistance confirm thermal resistance determined by common laboratory testing
  → common laboratory testing is also valid for IR reflective insulation