CLEAR SKY RADIATION – UNDERCOOLING CONDENSATION

1. Introduction

Due to clear sky radiation the external building envelope surface temperature can be lower than the outdoors air temperature. A roof edge, in which a condensation problem occurred in early spring, is simulated both under steady state and transient conditions. The case studies show that the clear sky radiation causes the condensation problem.

2. Case study subject

Figure 1. View on building roof edge and roof edge vertical section.

3. Steady state analysis

BISCO data roof_edge.bsc

The file roof_edge.bsc contains the complete data in BISCO format. We will discuss here some data highlights only.

- The **outdoors** is defined as a BC_SKY type.
  The air temperature is –4 °C, assuming a cold night in March (Belgian location).
  A convective surface heat transfer coefficient h_c = 6 W/m^{2}K is applied, assuming wind still weather.
  The sky temperature is –25 °C, i.e. 21 °C lower than the air temperature. Such value is experimentally proven for clear nights [1]. In this case this assumption might be too conservative, as the roof edge "looks" partially to the ground at a higher temperature.
- The **indoors** is defined as BC_SIMPL type. A resultant temperature of 20 °C and a global surface heat transfer coefficient h = 10 W/m^{2}K are assumed.
- The material **thermal conductivities λ** were taken from EN ISO 10456.
- The **glazing cavity** is defined as a TRANSMAT type. Still argon with λ = 0.017 W/mK (EN 673, ref. [3]) and a low emissivity (ε = 0.05) coating on the external pane are assumed.
- Also the **large cavity** between glazing and woodwool-cement board is defined as a TRANSMAT type. As air will be not still in this cavity (thickness 35 mm), λ = λ_{air} Nu is assumed with a Nusselt number Nu = 2.5 [4].

- The **frame cavities** are EQUIMAT types. The heat flow direction (X or Y) is automatically calculated at each time step (Calculation Parameter window). For the frame cavities completely surrounded by aluminium λ = 0.2 W/mK is used. Using a more precise value has no relevance for such cavities.
- The **long wave emissivity ε** of all [1]material surfaces is 0.9, except for the glazing surfaces that have a long wave emissivity ε = 0.84 according to EN 673 (ref. [3].) and for the low emissivity coating.
- **Non-linear radiation** is specified in the calculation parameters.

Figure 2 shows the simulated temperature course in the roof. The effect of the clear sky radiation is quite clear. Even the temperature at the internal side of the double glazing is negative. Due to air and/or vapour diffusion leakages between the indoors and the large cavity between double glazing and woodwool board, warm humid air can diffuse into the large cavity and condensation that freezes on the glazing occurs.

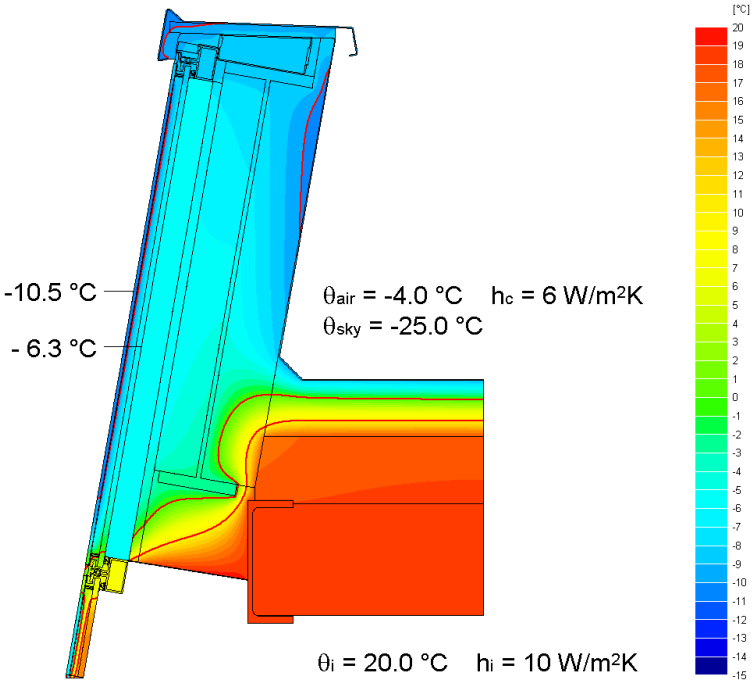

Figure 2. Temperature course in the roof edge.

4. Transient analysis

BISCO data roof_edge_transient.bst

In the transient analysis both the clear sky radiation and the solar radiation are considered. The roof edge on a clear sky day period (7 March) is simulated. The outdoor air and sky temperature course is shown in Figure 5. The horizontal global and diffuse solar radiation course is shown in Figure 3. These climate data were obtained from Meteonorm. The sky temperature θ was calculated from the incoming longwave radiation I_{IR} using the formula

$\theta_{sky} = \sqrt[4]{I_{IR}/\sigma} - 273.16$ with σ = 5.670E-08 W/m^{2}K^4 (Stefan-Boltzmann constant).

On a yearly basis the maximum difference between the air temperature and the sky temperature is 21.6 °C, a value that corresponds well with the maximum of 21 °C used in the steady state analysis, retrieved from reference [1].

[1] Only for material surfaces that are in direct contact with a BC_FREE, BC_SKY or TRANSMAT type the value of the long wave emissivity is taken into account in the simulation.

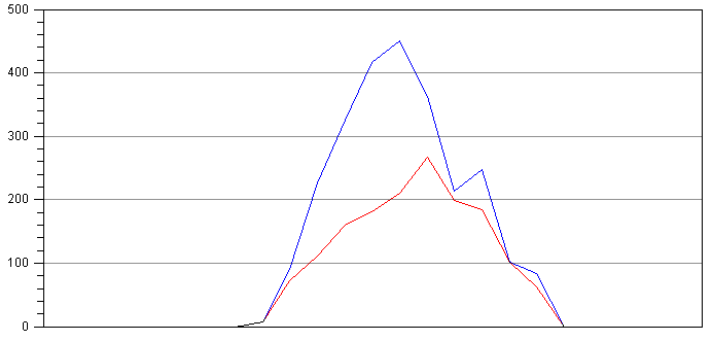

Figure 3. Horizontal global and diffuse solar radiation on 7 March.

Complementary to the steady state data discussed above, transient data highlights are the following:

- The **material properties** density **ρ** and specific heat **c** were taken from ISO 10456 (ref. [2]).
- For the outdoors air and sky temperature and for the horizontal global solar radiation time functions are used:
  Ukkel-MN4.FTE, Ukkel-MN4_sky.FTE, Ukkel-MN4.FSG and Ukkel-MN4.FSD
- The façade is oriented to North-East-East (20° from the East). Therefore, in the Solar Data window the North is defined using 3 angles: 0°, 90° (vertical section) and 110° according to the conventions used in BISTRA. A ground reflection coefficient of 0.20 is assumed. When the sun altitude is lower than 5°, no direct solar radiation occurs (see Solar Obstacles window).
- In the Calculation Parameters window, day 66 (7 March) is defined. A time step of 10 minutes is used.
- The solar absorption of both glazing panes is 0.1. The solar transmittance (after deduction of reflection) of both glazing panes is 0.8. No angle dependent solar reflection is considered.
- A temperature sensor (colour 19) is applied at the internal double glazing surface. In the Report Definition window, the registration of its temperature and of the air and sky temperature is specified.
- The **solar transmittance** of opaque materials is $\tau_s = 0$. Dark coloured surfaces are assumed for all opaque materials that can receive solar radiation. Therefore a **solar reflectance** $\rho_s = 0.1$ (and thus $\alpha_s = 0.9$) is used for all materials, except for the floor surface for which $\rho_s = 0.4$ (and thus $\alpha_s = 0.6$ corresponding to an intermediate colour) is used.

Figure 4 shows the simulated temperature course at 08:00 and at 10:00. Figure 5 shows the temperature evolution in the temperature sensor (point A). During the night the glazing internal temperature is negative, causing freezing condensation. In the morning this surface suddenly heats up. The ice layer melts suddenly and flows through leakages to the indoors.
The dynamic results for March 7th can be seen in:

- Animation1.avi
- Animation2.avi

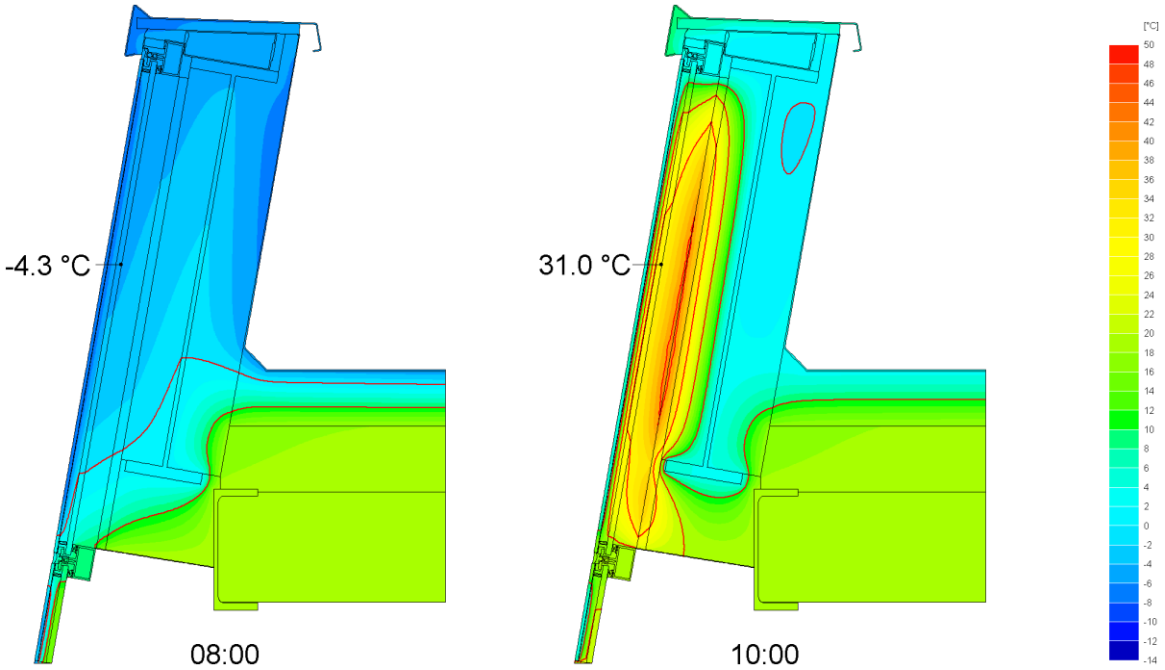

Figure 4. Temperature course at 08:00 and 10:00.

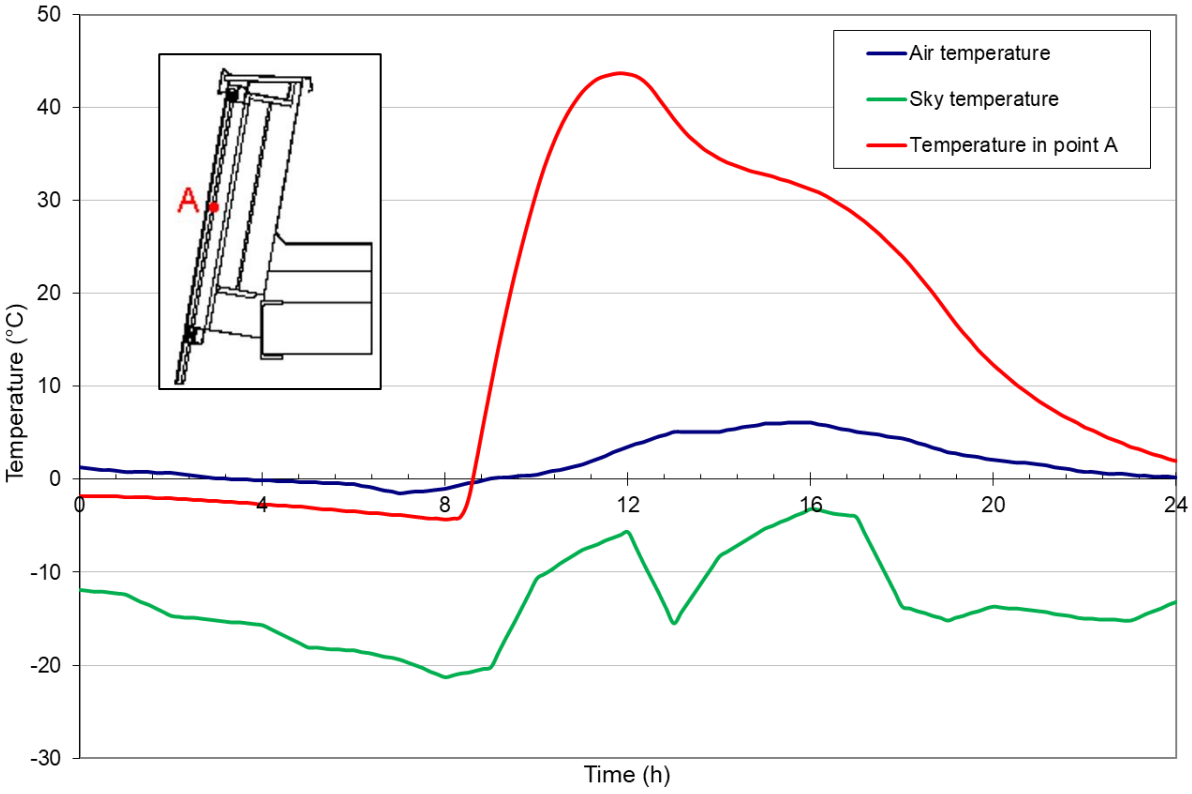

Figure 5. Temperature evolution on 7 March, outdoors air and sky, and internal glazing surface.

5. References

[1] Building Physics – Heat, Air and Moisture, Hugo Hens, 2007, ISBN 978-3-433-01841-5
[2] EN ISO 10456: Building materials and products – Hygrothermal properties – Tabulated design values and procedures for determining declared and design thermal values
[3] EN 673:2011: Glass in building – Determination of thermal transmittance (U value) – Calculation method
[4] Physibel Software Pilot Book - THERMAL SIMULATION OF NON-VENTILATED CAVITIES USING THE RADCON MODULE
[5] Physibel Software Pilot Book - THERMAL ANALYSIS OF THE BUILDING ENVELOPE IN SUMMER CONDITIONS - PART II: TRANSPARENT CONSTRUCTIONS