CLEAR SKY RADIATION VISUAL VALIDATION

1. Introduction

This document discusses the occurrence of hoarfrost due to clear sky radiation.
The first case study discusses formation of frost on the external glazing surface of a roof window.
The second case studies the frost pattern on a car, only partly parked in a garage.
Both cases are simulated as a steady-state problem using the program TRISCO with RADCON.

Figure 1. hoarfrost pattern on left) external side of a roof window and right) car partly parked in a carport

2. Case study 1: roof window

TRISCO data wooden_frame_glazed.trc

The pictures in Figure 2 show a clear frost pattern on the external glazing surface of a wooden roof window together with the corresponding TRISCO model.

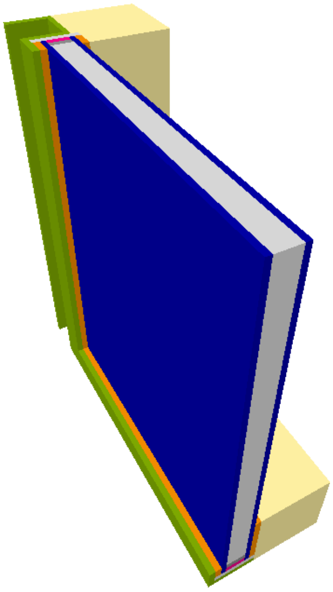

Figure 2. Left) Roof window with hoar-frost and right) TRISCO model

Col.		Type	CEN-rule	Name	Pat.	λ [W/mK]	ε [-]	θ [°C]	h [W/m²K]	q [W/m²]	θa [°C]	hc [W/m²K]	Pc [W]	θr [°C]	C1	C2	C3
8		MATERIAL		aluminium		160.000	0.90										
11		MATERIAL		stainless steel		17.000	0.90										
15		MATERIAL		softwood		0.130	0.90										
18		MATERIAL		soda lime		1.000	0.84										
60		MATERIAL		EPDM		0.250	0.90										
62		MATERIAL		silicone		0.350	0.90										
170		BC_SKY	NIHIL	exterior						0	0.0	6.00		-20.0			
174		BC_SKY	NIHIL	interior (normal)						0	20.0	3.00		20.0			
214		EQUIMAT	NIHIL	equivalent U = 1.5 W/m2K		0.033	0.90										
215		EQUIMAT	CEN_Yx_I	cavity (CEN)		0.167	0.90								0.025	1.14	0.333333
216		EQUIMAT	CEN_Yz_I	cavity (CEN)		0.167	0.90								0.025	1.14	0.333333

Figure 3. TRISCO data – part colour properties.

Figure 3 shows the TRISCO Colours window in which the properties of materials (thermal conductivity, surface emissivity), cavities (equivalent thermal conductivity) and boundary conditions are defined.

We will discuss here some data highlights only.

- The **outdoors** is defined as a BC_SKY type.
  The air temperature is 0 °C, assuming a cold night in March (Belgian location).
  A convective surface heat transfer coefficient h_c = 6 W/m²K is applied, assuming wind still weather.
  The sky temperature is –20 °C, i.e. 20 °C lower than the air temperature. Such value is experimentally proven for clear nights.
- The **indoors** is defined as BC_SKY type. Both the air temperature and the radiation temperature are 20 °C. A convective surface heat transfer coefficient h_c = 3 W/m²K is assumed.
- The material **thermal conductivities λ** were taken from EN ISO 10077-2.
- The **glazing cavity** is defined as an EQUIMAT type. The equivalent thermal conductivity is chosen in order to get a glazing thermal transmittance U_g = 1.5 W/m²K.
- 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.
- **Non-linear radiation** is specified in the calculation parameters.

Figure 4 shows the temperatures on the external surface. The shape and the location of the coldest zone correspond very well to the frost zone.

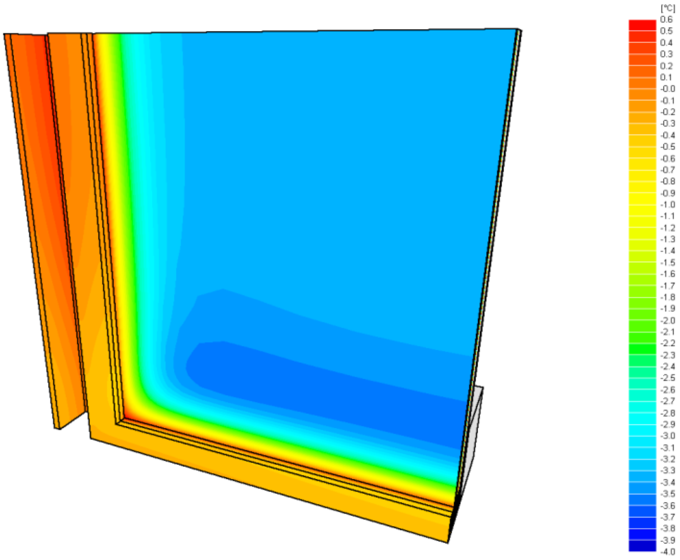

Figure 4. Temperature field on the external surface.

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

3. Case study 2: partial hoarfrost on car

BISCO data car.bsc
TRISCO data car_T.trc
TRISCO data car_frost_T.trc

The right picture in Figure 1 shows the frost pattern on a car being partly parked overnight in a garage. The back of the cars roof is covered with frost while the front of the cars roof not.
This situation is simulated both in BISCO and in TRISCO as a 2D steady-state problem.
The model is generated by loading the DXF file car.dxf in BISCO (car.bsc). The BISCO model is then imported in TRISCO (car_T.trc).

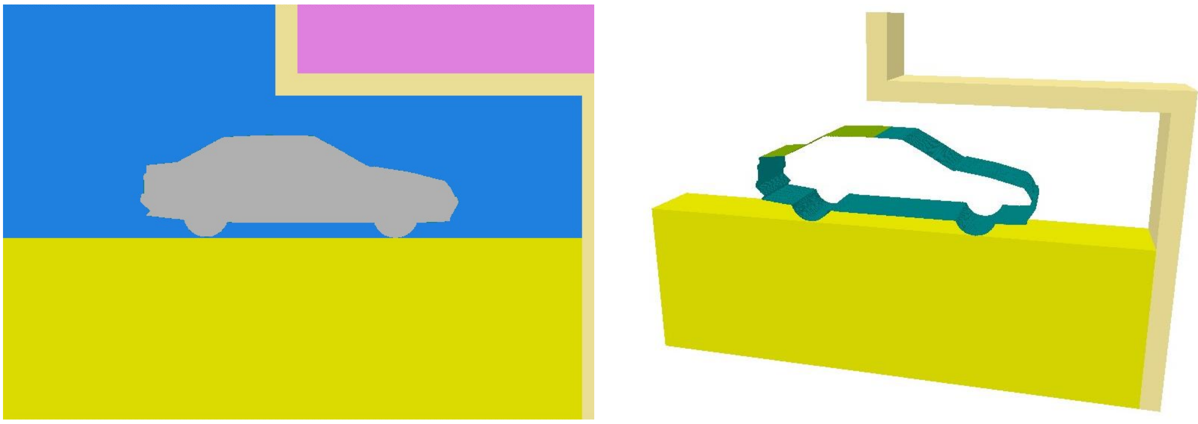

Figure 5. Left) model in BISCO Right) BISCO model imported in TRISCO.

Col.		Type	CEN-rule	Name	Pat.	λ [W/mK]	ε [-]	θ [°C]	h [W/m²K]	q [W/m²]	θa [°C]	hc [W/m²K]	Pc [W]	θr [°C]
11		MATERIAL		steel (hoarfrost)		50.000	0.90							
13		MATERIAL		steel		50.000	0.30							
15		MATERIAL		insulation wall/roof		0.040	0.90							
23		MATERIAL		sand and gravel		2.000	0.90							
170		BC_SKY	NIHIL	exterior						0	2.0	6.00		-20.0
174		BC_SIMPL	NIHIL	interior (normal), horizontal heat flow				20.0	7.70	0				
190		BC_SIMPL	NIHIL	ground				10.0	1000.00	0				
192		BC_FREE	NIHIL	zone						0		2.50	0	

Figure 6. TRISCO data – part colour properties.

Figure 6 shows the TRISCO Colours window in which the properties of materials (thermal conductivity, surface emissivity) and boundary conditions are defined.
We will discuss here some data highlights only.

- The **car** is treated as a perfectly mixed air zone BC_FREE type surrounded with a 2 mm thick steel plate.
- The **long wave emissivity ε** of the whole car surface is assumed in a first simulation to be 0.3 (car_T.trc).
- The **outdoors** is defined as a BC_SKY type.
  The air temperature is 2 °C, assuming a cold night.
  A convective surface heat transfer coefficient h_c = 6 W/m²K is applied, assuming wind still weather. The sky temperature is −20 °C.
- The **long wave emissivity ε** of the whole car surface is assumed in a first simulation to be 0.3 (car_T.trc).
- **Non-linear radiation** is specified in the calculation parameters.

Figure 7 (left) shows the temperature profile for this situation. It can be seen that the back of the cars roof is colder than the front. As a result, under specific conditions, it is likely to happen that ice formation on the back of the roof occurs while not at the front.

When hoarfrost happens, the emissivity of the car surface increases. For this reason a second simulation is made in which the emissivity at the back of the car is increased to 0.9 (car_frost_T.trc). Figure 7 (right) illustrates that this secondary effect further decreases the temperature at the back of the car and thus locally increases the ice formation there.

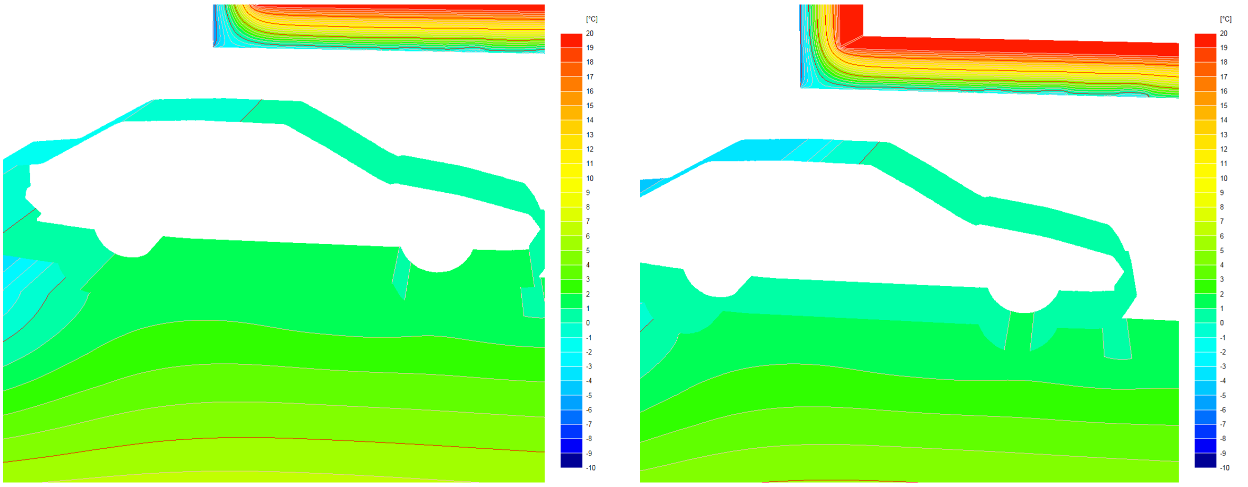

Figure 7. Left) Temperature profile with cars emissivity of 0.3 and Right) Temperature profile with increased car emissivity (0.9) due to hoarfrost formation.

When adjusting the temperature scale to negative temperatures only, Figure 8 clearly shows that the model produces a very similar frost pattern due to clear sky undercooling.

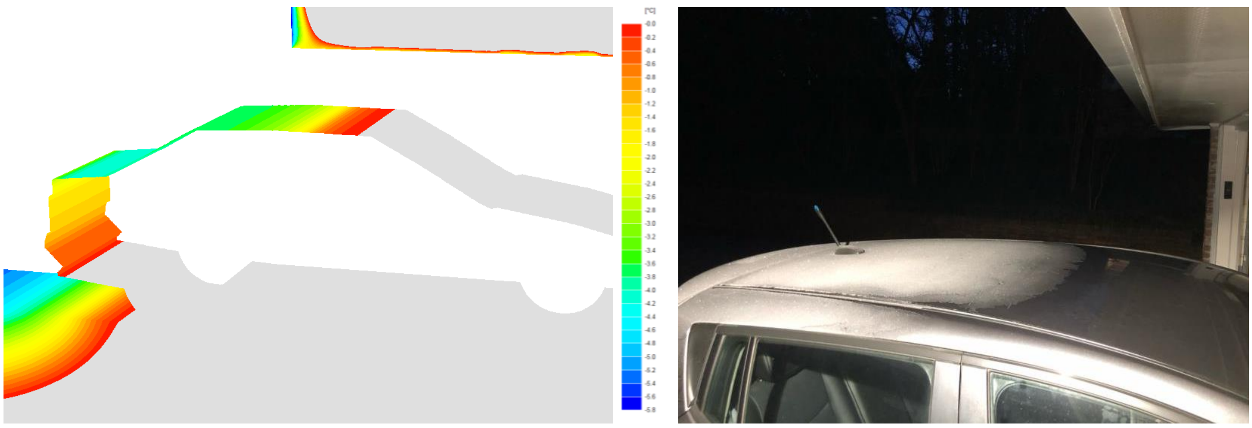

Figure 8. Comparison between model (e=0.9) and reality (temperature scale below 0°C).

4. References

EN ISO 10077-2:2017 Thermal performance of windows, doors and shutters - Calculation of thermal transmittance - Part 2: Numerical method for frames

EN 673:2011 Glass in building - Determination of thermal transmittance (U value) - Calculation method