

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.

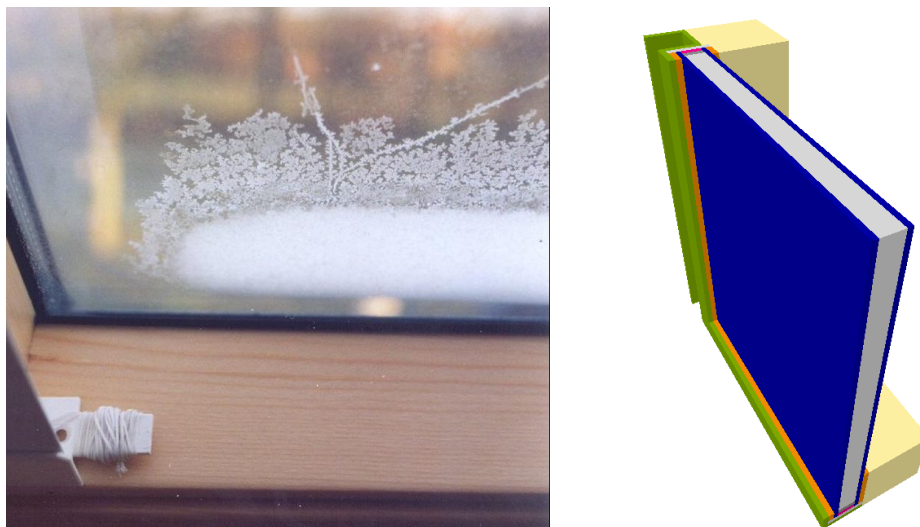


Figure 2. Left) Roof window with hoar-frost and right) TRISCO model

Col.	Type	Subtype	Physical flow dir.	Geometrical flow dir.	Name	ϵ_1 / ϵ_2 [- / -]	λ [W/mK]	ϵ [-]	θ [°C]	h [W/m²K]	q [W/m²]	θ_a [°C]	h_c [W/m²K]	P_c [W]	θ_r [°C]	Standard
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								NIHIL
215	EQUIMAT	CAVITY	UP	Yx	cavity (CEN)	0.90 / 0.90	0.167	0.90								EN6946
216	EQUIMAT	CAVITY	UP	Yz	cavity (CEN)	0.90 / 0.90	0.167	0.90								EN6946

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 $h_c = 6 \text{ W/m}^2\text{K}$ 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 $h_c = 3 \text{ W/m}^2\text{K}$ 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 $U_g = 1.5 \text{ W/m}^2\text{K}$.
- The **long wave emissivity** ϵ of all¹ material surfaces is 0.9, except for the glazing surfaces that have a long wave emissivity $\epsilon = 0.84$ 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.

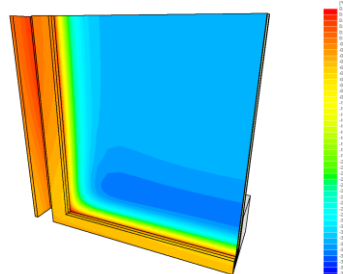


Figure 4. Temperature field on the external surface.

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](#)).

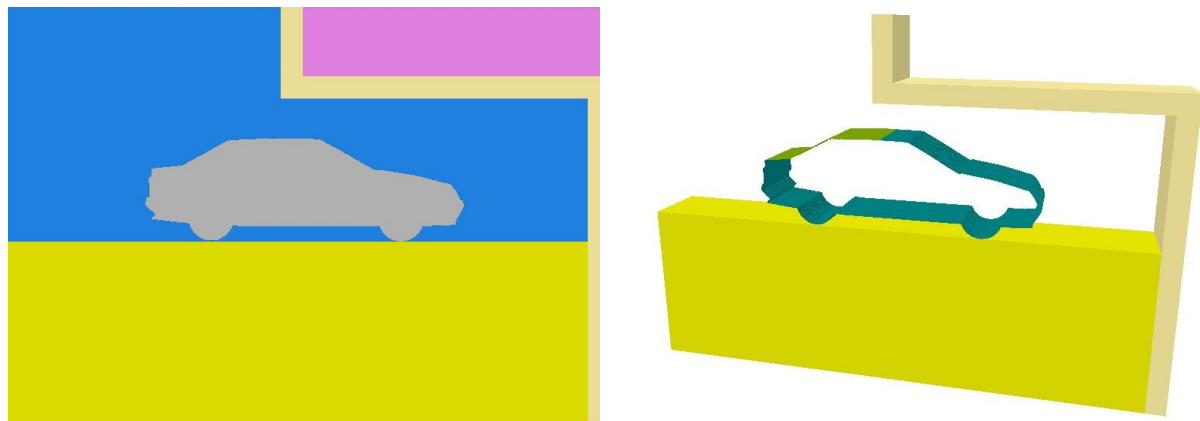


Figure 5. Left) model in BISCO Right) BISCO model imported in TRISCO.

Col.	Type	Subtype	Physical flow dir.	Geometrical flow dir.	Name	ϵ_1 / ϵ_2 [- / -]	λ [W/mK]	ϵ [-]	θ [°C]	h [W/m²K]	q [W/m²]	θ_a [°C]	h_c [W/m²K]	P_c [W]	θ_r [°C]	Standard
11	MATERIAL				steel (hoarfrost)		50.000	0.90								
13	MATERIAL				steel		50.000	0.30								
15	MATERIAL				insulation		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					NIHIL
190	BC_SIMPL	NIHIL			ground				10.0	1000.00	0					NIHIL
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 the 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 $h_c = 6 \text{ W/m}^2\text{K}$ is applied, assuming wind still weather. The sky temperature is -20 °C.

- The **long wave emissivity** ϵ of the back of the car surface is assumed in the second simulation to be 0.9 ([car frost 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.

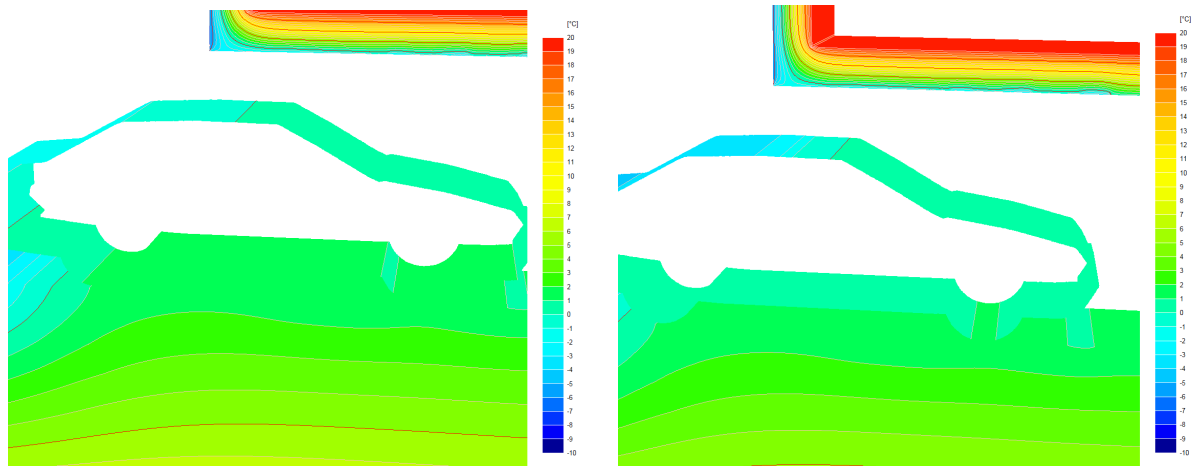


Figure 7. Left) Temperature profile with cars emissivity of 0.3 and Right) Temperature profile with increased car emissivity (0.9) due to hoarfrost formation.

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.

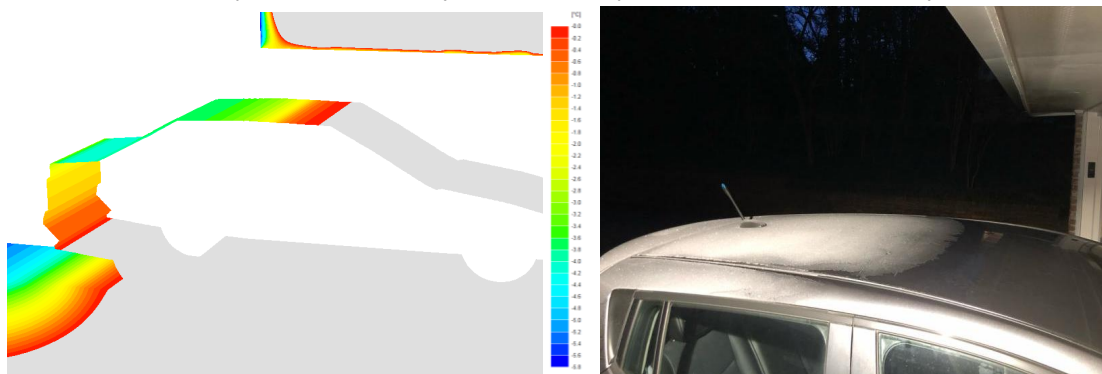


Figure 8. Comparison between model (e=0.9) and reality (temperature scale below 0°C).

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