SIMULATING 2D&3D INTERSTITIAL CONDENSATION USING THE PROGRAMS BISCO and TRISCO/SOLIDO

1. Introduction

BISCO is designed for simulating two-dimensional steady state heat transfer. However, as the governing mathematical equations for vapour diffusion are similar to the ones for heat transfer, the program can be used for simulating vapour diffusion as well. The document explains how to use BISCO to predict interstitial condensation in a construction detail. The same principles can be applied to calculate interstitial condensation in 3D with the programs TRISCO or SOLIDO.

2. Background: similarity between heat conduction and vapour diffusion

The transport equation for heat conduction (Fourier's law):

$$q_{cond} = -\,\lambda.grad\ (\theta)$$

q_c	conductive heat flux – W/m²
λ	Thermal conductivity – (W/m.K)
θ	Temperature – °C

The transport equation for vapour diffusion (Fick's law) transport:

$$g_{vap,dif} = -\,\frac{1}{\mu.N}.grad\ (p_v)$$

$g_{vap,dif}$	vapour diffusion flow – kg/(m².s)
μ	diffusion resistance number (–)
p_v	vapour pressure (Pa)
N	air diffusion constant (5.4 10^9 1/s)

For background theory on humid air and condensation: see Knowledge base F.1. and F.2

3. Example data

The figure below defines the example data. The left and right borders are adiabatic (or symmetric axes).

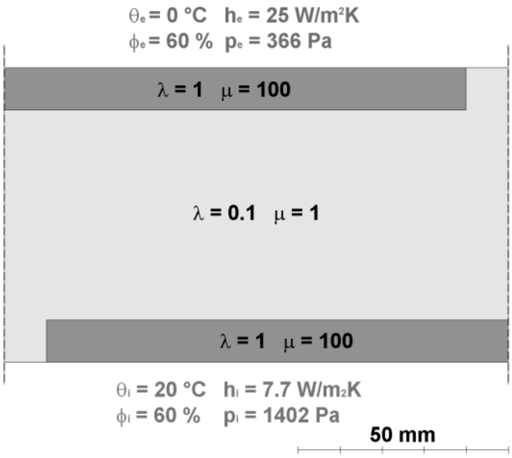


Figure 1. Example geometry, material properties and boundary conditions

4. Calculation procedure

Step 1: thermal simulation.

Bisco data: example_2D_IC_step1.bsc.
Figure 2 shows the temperature distribution within the object.

Step 2: conversion of temperatures into saturation vapour pressures.

Copy the files	example_2D_IC_step1.bsc	to	example_2D_IC_step2.bsc
	example_2D_IC_step1.tri	to	example_2D_IC_step2.tri
	example_2D_IC_step1.sol	to	example_2D_IC_step2.sol.

Open the file example_2D_IC_step2.sol in a spreadsheet program.
The lines starting with "N " contain the node temperatures.
Convert the node temperatures into the saturation vapour pressures.
The file saturation_vapour_pressure.xlsm can be used to make this conversion.
Save the file example_2D_IC_step2.sol.
After opening the data example_2D_IC_step2.bsc in BISCO, without doing a calculation (!), a graphic output showing the saturation vapour pressures is now available: Figure 3.

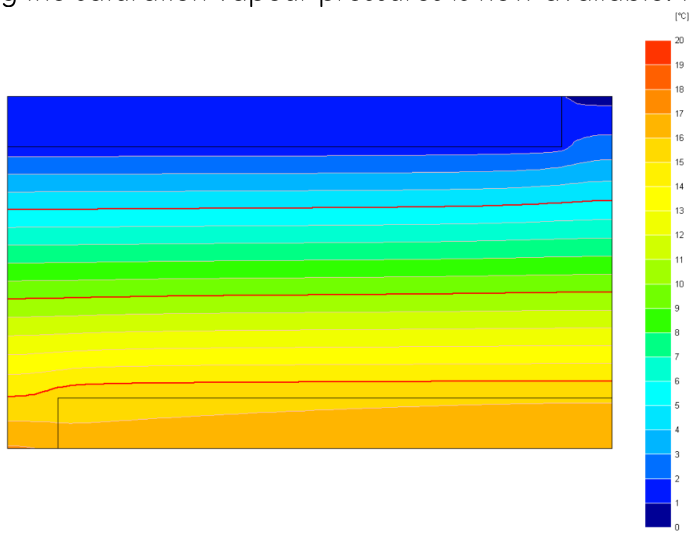


Figure 2. Result of step 1: temperature distribution

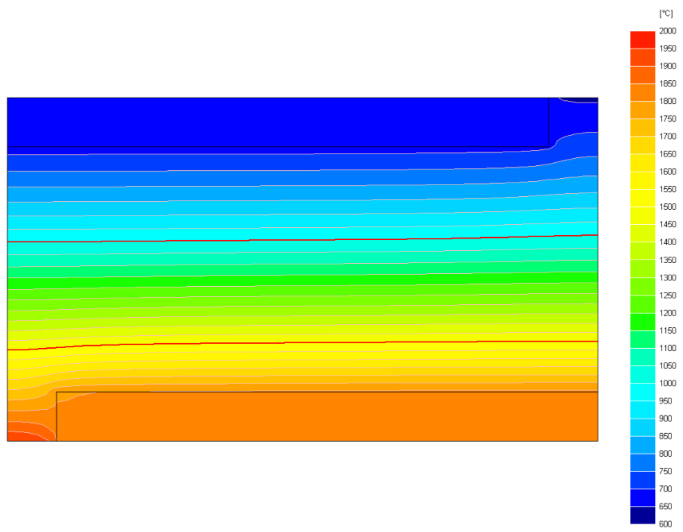


Figure 3. Result of step 2: saturation vapour pressure distribution

Step 3: vapour diffusion simulation.

Bisco data: example_2D_IC_step3.bsc.

In order to do a vapour diffusion simulation:

- for the λ-value use $1/\mu$ [-]
- for the θ-value use the vapour pressure [Pa]
- for the h-value use a high value (e.g. 1000) assuming a negligible surface diffusion resistance.

Colours

Col.		Type	Subtype	Physical flow dir.	Geometrical flow dir.	Name	ε1 / ε2 [- / -]	λ [W/mK]	ε [-]	θ [°C]	h [W/m²K]	q [W/m²]	θa [°C]	hc [W/m²K]	Pc [W/m]	θr [°C]	Standard
23		MATERIAL				lambda 0.1 W/mK / mu 1		1.000									
59		MATERIAL				lambda 1 W/mK / mu 100		0.010									
170		BC_SIMPL	NIHIL			exterior vapour pressure				366.0	1000.00	0					NIHIL
174		BC_SIMPL	NIHIL			interior vapour pressure				1402.0	1000.00	0					NIHIL

The vapour pressure distribution obtained is shown in Figure 4. However, this result is false because in some locations, the vapour pressure is higher than the saturation vapour pressure (Figure 3), which is physically impossible. This will be corrected in step 4 and 5.

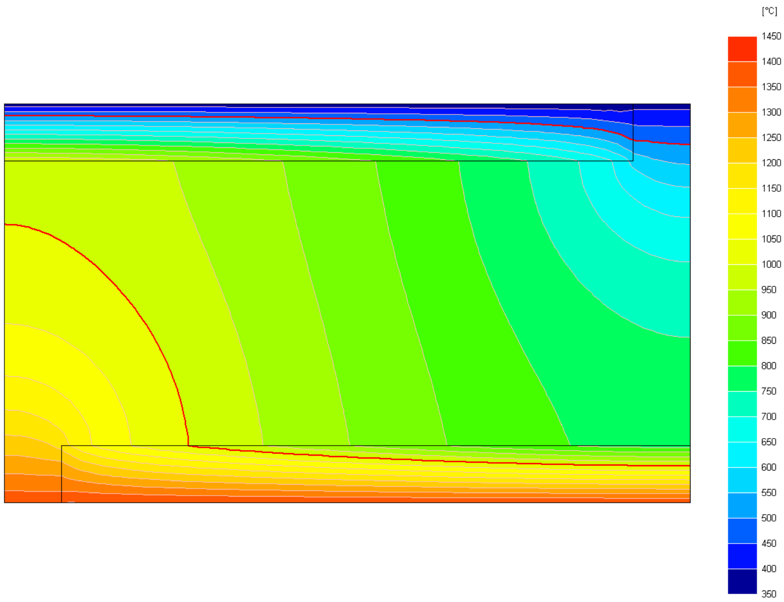


Figure 4. Result of step 3: vapour pressure distribution

Step 4: locating the interstitial condensation.

Copy the files example_2D_IC_step3.bsc to example_2D_IC_step4.bsc
example_2D_IC_step3.tri to example_2D_IC_step4.tri
example_2D_IC_step3.sol to example_2D_IC_step4.sol.

Open the files example_2D_IC_step2.sol and example_2D_IC_step4.sol in a spreadsheet program.

The lines starting with "N " contain the node "temperatures" (being pressures).

Subtract the values in example_2D_IC_step4.sol from the values in example_2D_IC_step2.sol, and put the results in the file example_2D_IC_step4.sol and save this file.

After opening the data [example_2D_IC_step4.bsc] in BISCO, without doing a calculation (!), a graphic output showing the difference between the saturation vapour pressures (step 2) and the vapour pressures (step 3) is now available. Figure 5 shows the locations where the vapour pressure, as calculated in step 3, exceeds the saturation vapour pressure. The interstitial condensation will occur in this zone, and most likely in the interface between the 2 materials.

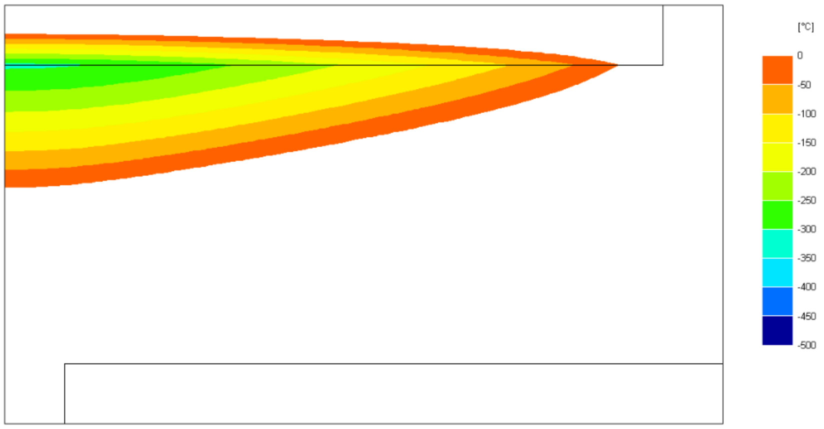
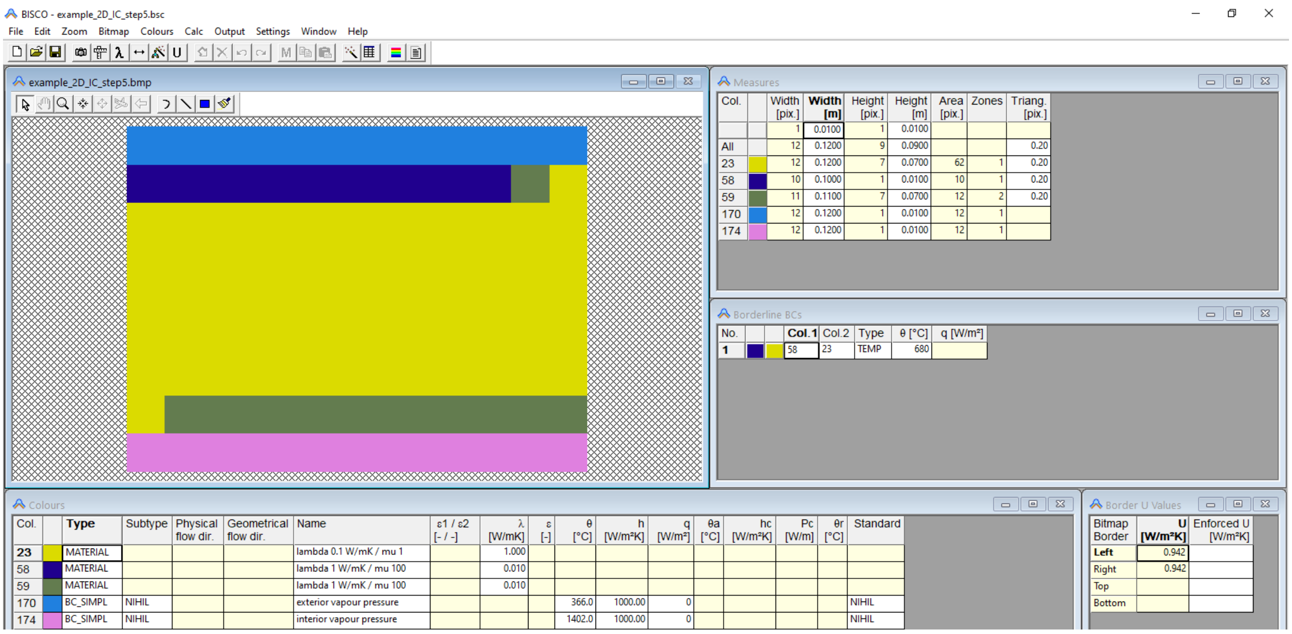


Figure 5. Result of step 4: zones with vapour pressure > saturation vapour pressure

Step 5: corrected vapour diffusion simulation.

Bisco data: example_2D_IC_step5.bsc.

In order to limit the vapour pressure in the condensation interface to the saturation vapour pressure, a borderline boundary condition is applied in the interface. A saturation vapour pressure of 680 Pa is applied as a known "temperature" in the interface. The value of 680 Pa can be derived from step 2 (Figure 3). The simulation results in a corrected vapour pressure distribution as shown in Figure 6. Also the 'heat flow lines' are shown. They visualize the vapour arriving and leaving the interstitial condensation interface. The condensation amount can be derived from the difference between the 'heat' going in and the 'heat' going out of the object (listed in text output). This difference is 155 W/m. In order to convert this amount to kg/ms it should be divided by the air diffusion constant N = 5.4×10^{9} /s. Therefore, the amount is 2.87×10^{-8} kg/ms. During a month (31 days) the condensation amount would be 0.077 kg/m.



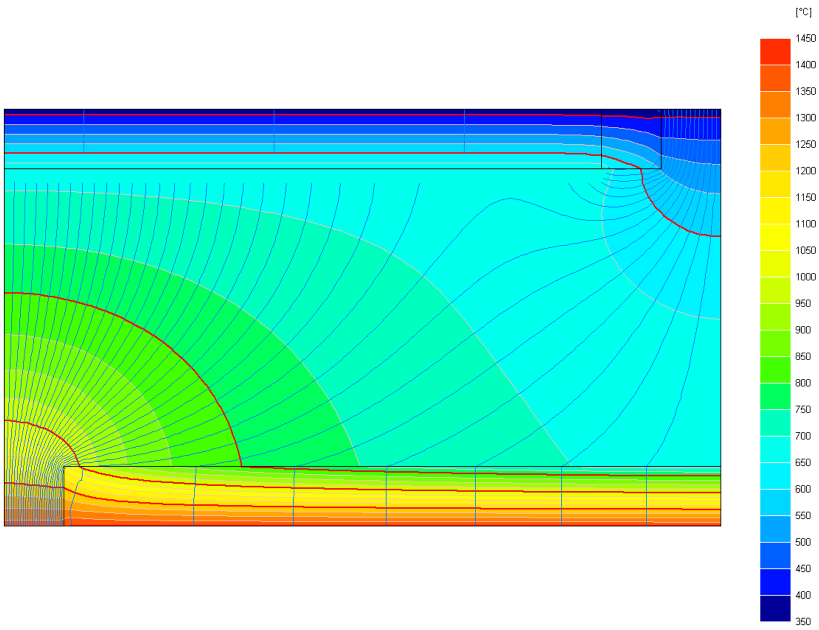


Figure 6. Result of step 5: corrected vapour pressure distribution

Step 6: relative humidity.

Bisco data: example_2D_IC_step6.bsc and example_2D_IC_step7.bsc

In order to visualise the relative humidity step 1 and step 2 can be repeated with the adjusted bitmap of step 5 (in order to maintain the same nodes arrangement in the .sol file).

Copy example example_2D_IC_step5.bsc to example_2D_IC_step6.bsc and repeat step 1. Calculate in a spreadsheet the corresponding saturation vapour pressures and calculate the relative humidity from the ratio between vapour pressures and the saturation vapour pressure.

Copy the files	example_2D_IC_step6.bsc	to	example_2D_IC_step7.bsc
	example_2D_IC_step6.tri	to	example_2D_IC_step7.tri
	example_2D_IC_step6.sol	to	example_2D_IC_step7.sol.

Open the file example_2D_IC_step7.sol in a spreadsheet and replace the temperatures with the relative humidity's. After opening the data example_2D_IC_step7.bsc in BISCO, without doing a calculation (!), a graphic output showing the relative humidity is now available: Figure 7.

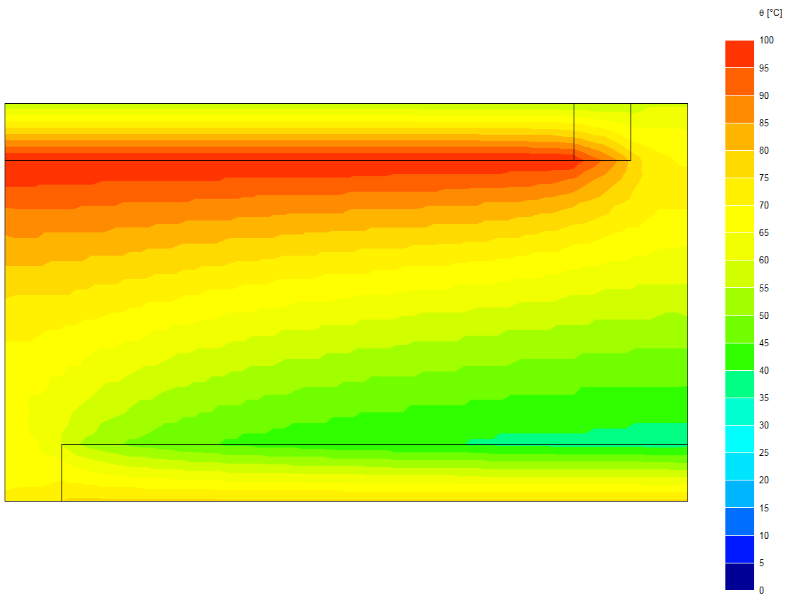
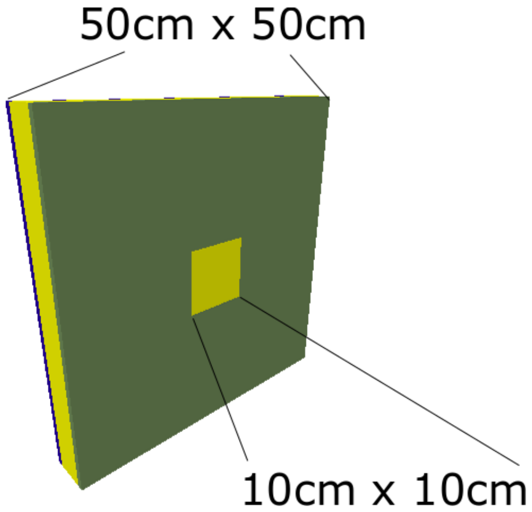


Figure 7. Result of step 6: relative humidity

5. 3D interstitial condensation with TRISCO

TRISCO data: example_3D_IC_step1.trc (example_3D_IC_step1.sol)
example_3D_IC_step2.trc (example_3D_IC_step2.sol)
example_3D_IC_step3.trc (example_3D_IC_step3.sol)
example_3D_IC_step4.trc (example_3D_IC_step4.sol)

Example data is



- Wall 50cm by 50cm
- Outer sheet 1cm: λ=1 and μ=10
- Middle part 7cm: λ=0.1 and μ=1
- Inner sheet 1cm: λ=1 and μ=100
- Hole in inner sheet (10cm by 10 cm)
- Inner conditions: 20°C and 1402 Pa
- Exterior conditions: 0°C and 366 Pa

The same procedure as for the 2D example with BISCO is followed. Because of symmetry only a quarter of the wall is modelled in TRISCO. The figure below shows the zones were the vapour pressure (step 3) is higher than the saturation vapour pressure. This is an indication of the interstitial condensation zone (insulation clipped in figure).

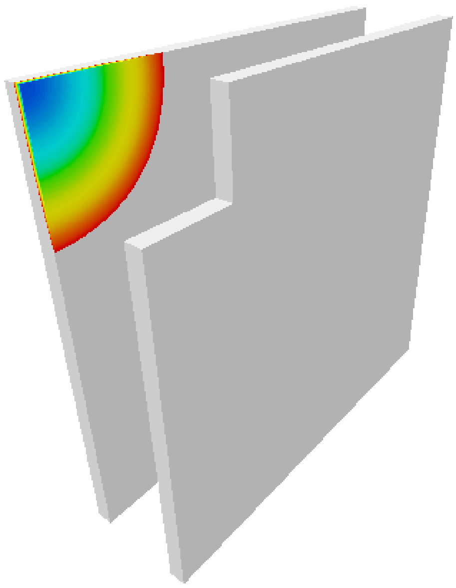


Figure 8. Result of step 4: zones with vapour pressure > saturation vapour pressure: condensation