



TUTORIAL
TRANSIENT SIMULATIONS OF VENTILATED DOUBLE SKIN
FAÇADE USING THE SOLAR PROCESSOR: VENTILATION
FLOWS AND CONTROL FUNCTIONS



VTR TUTORIAL B

1. Introduction

[T_VTR_b_ventilations_and_controls.vtr](#)

[T_VTR_a_solar_double_skin_facade_b_fine_grid.vtr](#)

This tutorial continues from the previous VOLTRA tutorial, "Transient Simulations of Ventilated Double Skin Façade Using the Solar Processor: Getting Started with VOLTRA." Therefore, it is highly recommended to complete that tutorial first. You may either continue using the final model from the previous exercise [T_VTR_a_solar_double_skin_facade_b_fine_grid.vtr](#) or start with the file referenced at the beginning of this tutorial.

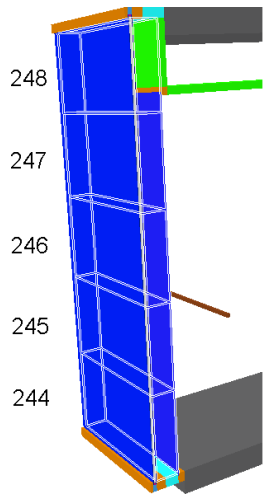
In this tutorial, we build on the earlier model by adding several enhancements to demonstrate forced and natural convective ventilation flows and control-function mechanisms within the double skin façade system.

Key elements:

- Comfort sensors
- Ventilation Flows parameters
- Double skin façade ventilation
- Constant and variable ventilation flow (forced and natural convection)
- Control Functions parameters

2. Modifications to the previous model

The double skin cavity in the previous tutorial (VTRa) is modelled as 1 single zone (BC_FREE with colour 240). We now divide this cavity into 5 parts (colours 244-248)- each of the type BC_FREE - to define cavity ventilation.



No.	Col.	Xmin	Xmax	Ymin	Ymax	Zmin	Zmax
31	244	15	25	0	1	9	33
32	245	15	25	0	1	33	57
33	246	15	25	0	1	57	81
34	247	15	25	0	1	81	105
35	248	15	25	0	1	105	129

Col.	Type	Subtype	Name	ϵ_1 / ϵ_2 [- / -]	c [-]	ρ [kg/m ³]	c [J/kgK]	θ [°C]	h [W/m ² K]	q [W/m ²]	θ_a [°C]	h_c [W/m ² K]	P_c [W]
244	BC_FREE	NIHIL	ventilated cavity part 1			1.2	1005			0		2.50	0
245	BC_FREE	NIHIL	ventilated cavity part 2			1.2	1005			0		2.50	0
246	BC_FREE	NIHIL	ventilated cavity part 3			1.2	1005			0		2.50	0
247	BC_FREE	NIHIL	ventilated cavity part 4			1.2	1005			0		2.50	0
248	BC_FREE	NIHIL	ventilated cavity part 5			1.2	1005			0		2.50	0

2 material blocks hanging in the room are added to the model as comfort temperature sensors.

In order to add these blocks, small modifications are made to the grid: X-grids 33-34 (100 mm) and 75-76 are divided into two grids (25 mm and 75 mm). This is done by selecting that cell → Grid → Split (CTRL + I) → Border 1 → 25 mm.

Figure 1 shows the positions of added sensor positions. Figure 2 displays the grid modifications. Figure 3 illustrates the material properties of the sensors and the block numbers. The sensor's solar absorption factor assumed is 0.5. Therefore the comfort measurement is affected by the solar radiation. By taking a zero solar absorption factor the effect of the sun on the comfort measurement could be excluded.

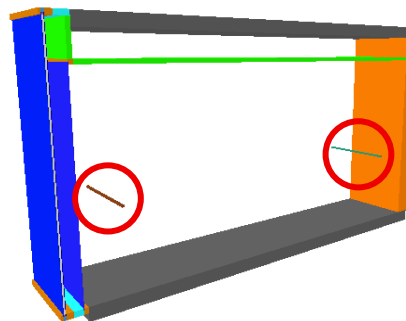


Figure 1 Comfort temperature sensors

Grid	
No.	X [mm]
Sum	5670.000
29-30	100.000
30-31	100.000
31-32	100.000
32-33	100.000
33-34	25.000
34-35	75.000

Grid	
No.	X [mm]
Sum	5670.000
73-74	100.000
74-75	100.000
75-76	25.000
76-77	75.000
77-78	100.000

Figure 2 Grid numbers and values after modification

Blocks							
No.	Col.	Xmin	Xmax	Ymin	Ymax	Zmin	Zmax
38	140	33	34	0	1	49	50
39	141	75	76	0	1	49	50

Colours									
Col.	Type	Name	λ [W/mK]	ϵ [-]	ρ [kg/m ³]	c [J/kgK]	ρ_S [-]	τ_S [-]	
140	MATERIAL	comfort sensor facade	100.000	0.90	100	1000	0.50	0.00	
141	MATERIAL	comfort sensor corridor	100.000	0.90	100	1000	0.50	0.00	

Figure 3 Block numbers and material properties of comfort temperature sensors

2 new output nodes are added on these sensors

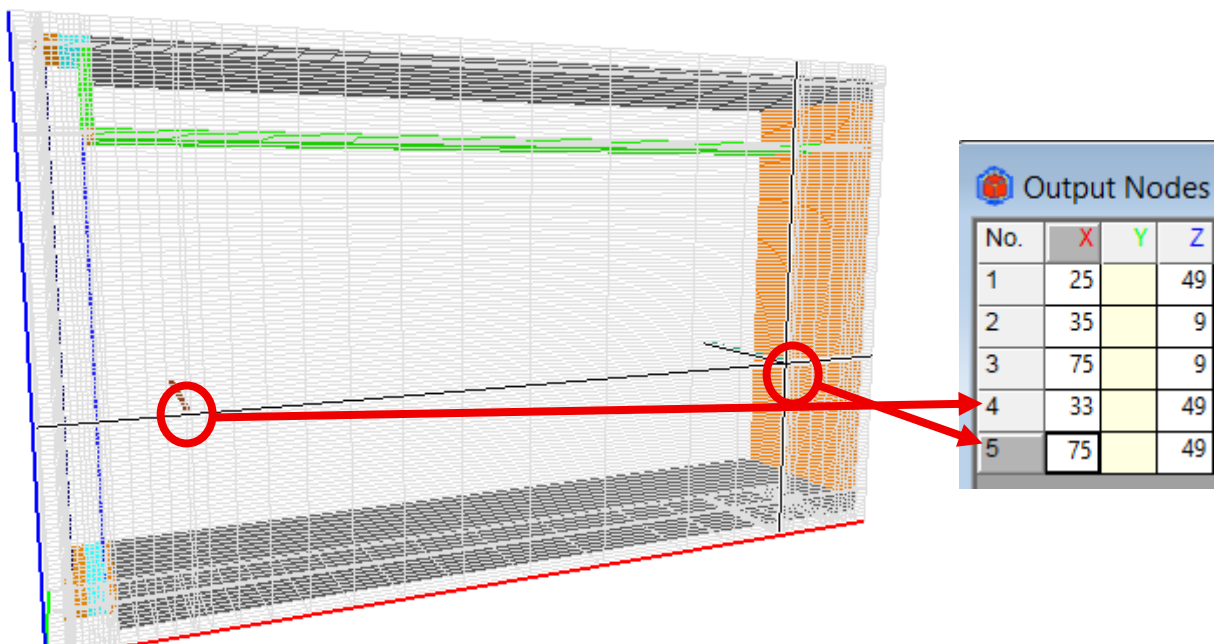


Figure 4 Output nodes

3. Constant ventilation flow

[T_VTR_b_constant_ventilation_flow_corrected.vtr](#)

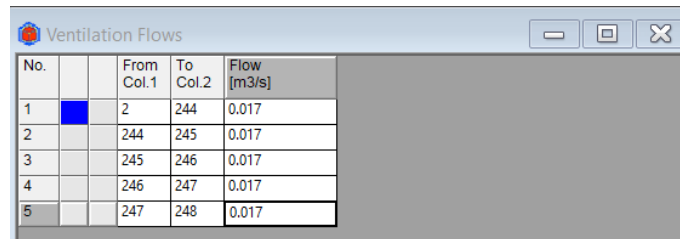
Figure 5 shows the Ventilation Flows window, which is accessible via *Edit* → *Ventilation Flows* (or CTRL + Alt + V).

A new row can be added via *Edit* → *Insert after*.

For each ventilation flow definition line a ventilation source and ventilation destination must be entered. Both are identified by colour numbers to the corresponding boundary conditions.

The ventilation source (in the column with header "From Col. 1") can be any type of boundary condition (BC_SIMPL, BC_FRE_S, BC_FREE, BC_SKY or BC_NOSKY). The ventilation destination (in the column with header "To Col. 2") must be a boundary condition of type BC_FRE_S or BC_FREE (with unknown air temperature influenced by the incoming ventilation flow). Please note that the ventilation source (From) and destination (To) must not be adjacent.

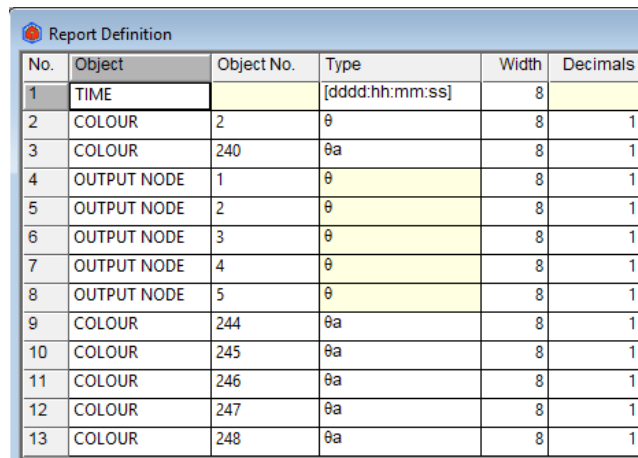
In this example, ventilation with outdoors air with a constant flow of 0.017 m³/s is assumed. It enters the facade through bottom and goes upward. It isn't necessary to specify where to the air from the zone 248 flows, as this doesn't affect the thermal behaviour of the object considered.



No.	From Col.1	To Col.2	Flow [m3/s]
1	2	244	0.017
2	244	245	0.017
3	245	246	0.017
4	246	247	0.017
5	247	248	0.017

Figure 5 Ventilation flows

Figure 6 displays the report definition. Two new sensor output nodes and newly divided cavity air temperatures have been added to the existing elements from the previous tutorial. Figure 7 shows the results.



No.	Object	Object No.	Type	Width	Decimals
1	TIME		[dddd:hh:mm:ss]	8	
2	COLOUR	2	θ	8	1
3	COLOUR	240	θa	8	1
4	OUTPUT NODE	1	θ	8	1
5	OUTPUT NODE	2	θ	8	1
6	OUTPUT NODE	3	θ	8	1
7	OUTPUT NODE	4	θ	8	1
8	OUTPUT NODE	5	θ	8	1
9	COLOUR	244	θa	8	1
10	COLOUR	245	θa	8	1
11	COLOUR	246	θa	8	1
12	COLOUR	247	θa	8	1
13	COLOUR	248	θa	8	1

Figure 6 Report definition

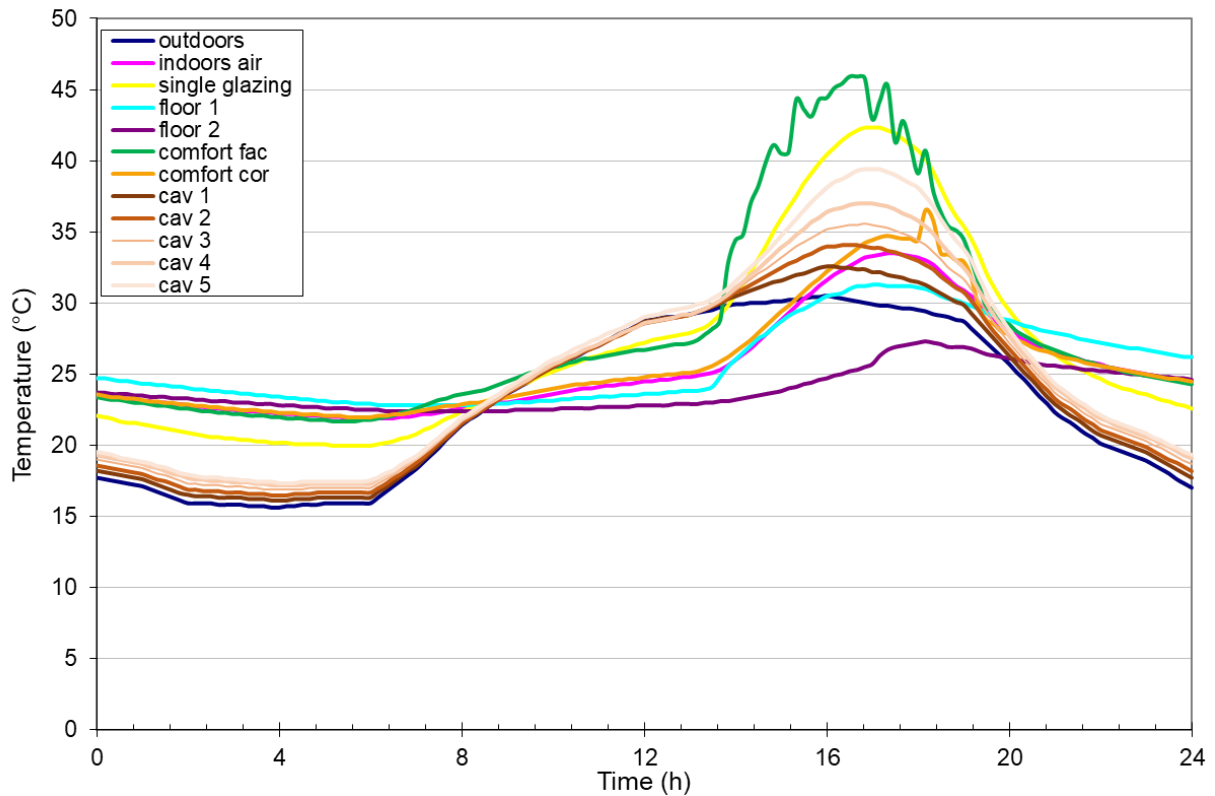


Figure 7 Temperature for specified points

4. Controls

[T_VTR_b_controls_corrected.vtr](#)

Controls in VOLTRA allow users to control various system functions depending on whether the objective is heating or cooling. At each defined time step, the sensor node value is compared with the target temperature to determine the appropriate control action.

In this tutorial, the constant ventilation flow defined in the previous step is controlled. The procedure is explained step-by-step, with the purpose of each parameter clarified to help users understand how the control strategy is implemented.

Controls window is accessible via Edit → Controls. New line can be added with Edit → Insert After

Figure 8 displays the parameters related to controls.

No.	Sensor node	θ target [T##]	Sens.up [°C]	Sens.dn [°C]	Purpose	Time on [min]	Time off [min]	Function from	Function to	Test Δθ	Δθ [°C]	Zone θ1	Zone θ2
1	5	T02	0.0	0.0	COOLING	0.0	0.0	V01	V02	YES	5.0	2	248

Figure 8 Controls window parameters

The Sensor Node refers to one of the model's output nodes. In this example, the selected output node is the comfort temperature sensor located in the corridor. At each time step, the temperature

at this sensor node is compared with the target temperature in order to activate or deactivate the control action.

The target temperature is defined as a temperature function. For this example, it is set to a constant value of 23 °C. Figure 9(left) shows the newly created functions used for the control configuration. Even a constant value must be defined as a function, because the target temperature parameter in the control settings only accepts function inputs.

Users can select either cooling or heating as the control purpose. When cooling is selected, the control action is activated whenever the sensor node temperature exceeds the target temperature. Opposite condition for heating. If the condition is fulfilled, the assigned function switches from the function defined in Function from to the function defined in Function to.

In this tutorial, both V01 and V02 are defined as constant values. V01 represents the no-ventilation case, while V02 corresponds to the scenario with constant ventilation of 0.017 m³/s.

As shown in Figure 9(right) , V01 is initially assigned in the Ventilation Flows window, indicating the default state of no ventilation. When the control condition is satisfied and the control action is triggered, VOLTRA automatically replaces all instances of V01 in this window with V02, thereby switching the system from no-ventilation to the defined constant-ventilation condition with the purpose of cooling here.

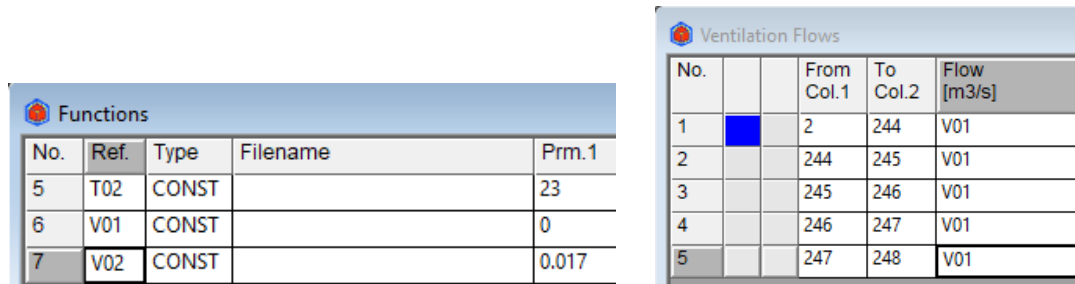


Figure 9 left) New functions for controls and right) Ventilation flows window with functions

If Test $\Delta\theta$ is set to YES, the target temperature is not the only parameter used to activate the control. For ventilation-flow functions, VOLTRA allows an additional comparison of temperatures along the ventilation path.

In this example, since the control purpose is Cooling, activation requires an extra condition: The temperature of the outside air (Colour 2) must be at least 5 °C lower than the temperature of the cavity (Colour 248, at top of the façade cavity). Only when both conditions are met, the control action is triggered.

The Sens. up and Sens. dn fields define the sensitivity thresholds for activating and deactivating the control action.

For Cooling:

- The control is activated when the sensor node temperature rises above:
 - o Target Temperature + Sens. up
- The control is deactivated when the sensor node temperature drops below:

- Target Temperature + Sens. dn

For Heating, the logic is reversed:

- The control is activated when the sensor node temperature falls below the threshold,
- And deactivated when it rises above it.

The Time on and Time off parameters allow the control action to remain on or off for a fixed minimum duration, regardless of sensor conditions.

For example, if Time on is enabled and not enough time has passed, the control action will remain active even if the sensor node temperature has already fallen below (Target + Sens. dn).

In this tutorial, both sensitivity values and timing parameters are set to zero, meaning the control responds immediately and solely based on the sensor and temperature comparison conditions.

No.	Object	Object No.	Type	Width	Decimals
12	COLOUR	247	θa	8	1
13	COLOUR	248	θa	8	1
14	CONTROL	1	ON	8	2

Figure 10 Control added to report definition

The control state can be displayed as an output in the report. To include it, the control state must be added to the report definition, as shown in Figure 10.

Figure 11 illustrates the results with control actions and Figure 12 shows the control state in the calculation period.

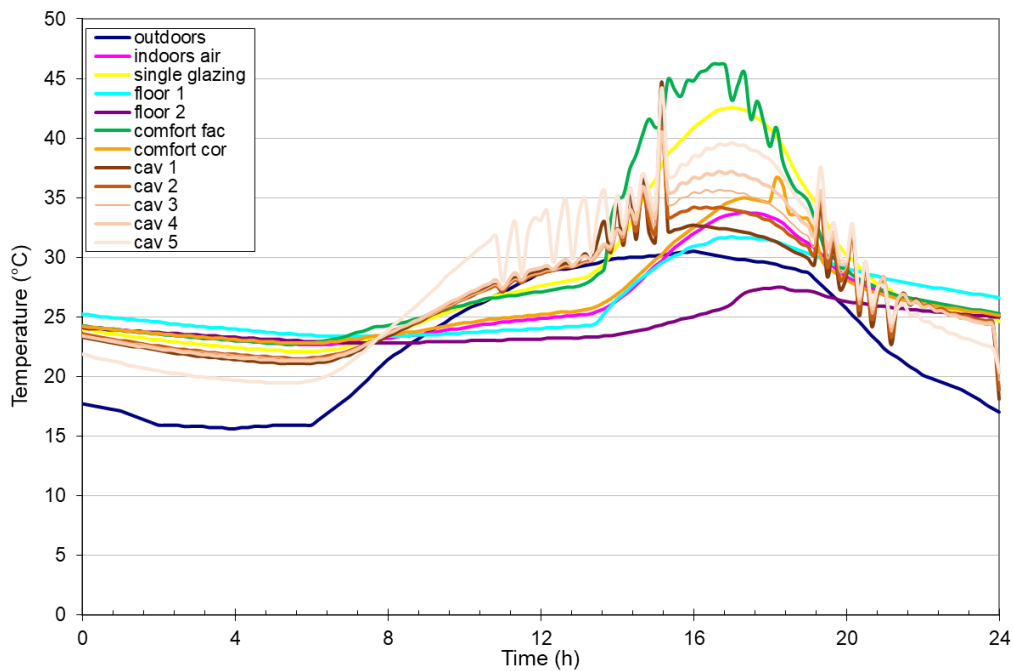


Figure 11 Temperature for specified points

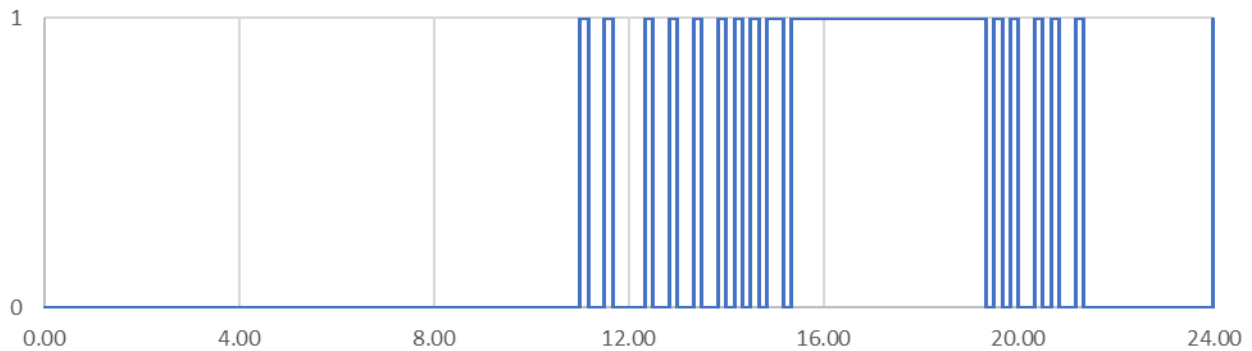


Figure 12 Control state vs time

Table 1 Text output of a selected period

Time	Temperature (°C)			Control (0 = off, 1 = on)
	Sensor node 5	Outdoor (Colour 2)	Cavity (Colour 248)	
13:30:00	25.9	29.5	33.9	0
13:40:00	26.2	29.7	35.6	0
13:50:00	26.5	29.8	31.4	1
14:00:00	26.9	29.9	35.2	0
14:10:00	27.3	29.9	32.6	1
14:20:00	27.8	30	35.8	0
14:30:00	28.3	30	34	1

Table 1, presents the text output between 13:20 and 14:30. During this entire period, the temperature measured by sensor node 5 remains above the target temperature of 23 °C. However, the control action is not continuously active because it also depends on a second condition.

The green-highlighted cells indicate moments when the outdoor temperature (=inlet temperature) is at least 5°C colder than cavity temperature (measured at the top of the cavity, colour 248). When this happens, the second condition is satisfied. As a result, the control becomes active in the next time step.

In contrast, the orange-highlighted cells indicate that this temperature difference is less than 5°C. In these cases, the second condition is not met, so the control remains inactive in the next time step.

Although this tutorial focuses on controlling ventilation functions, the Controls feature in VOLTRA can be used to manage a wide range of other system functions as well. For further details, users can refer to Knowledge Base document [C17 - Applications of control functions in VOLTRA](#) .

5. Varying ventilation flow

[T VTR b varying ventilation flow corrected.vtr](#)

Instead of a constant mechanical ventilation flow (Section3) a buoyancy driven ventilation flow (as a function of the temperature difference) is considered in this section. Gaps of 1cm wide are assumed, one at the bottom of the cavity and the other at the top of the cavity.

Using the spreadsheet file [T VTR b air cavity stack effect.xlsm](#) (Figure 13) the ventilation flow can be calculated as a function of the temperature difference between the cavity and the outdoors. (see also the Physibel Knowledge base document: [C24 - Air cavity – Stack effect simulation](#))

$$Q_m = b \cdot \theta^{0.5} \text{ [m}^3\text{/s]}$$

b [m³/sK^{0.5}] coefficient depending on H, D, L, θ_e , ξ_1 and ξ_2 . For this example, the average outdoor temperature for the calculation day is used to determine the value of b.

$$Q_m = 0.00364\Delta\theta^{0.5} \text{ [m}^3\text{/s]}$$

Calculation of thermal-driven ventilation through an air cavity with a rectangular cross section			
To use this sheet properly, Excel add-in solver should be installed			
environmental temperature	$\theta_e =$	23.0	°C
cavity temperature	$\theta_i =$	25.0	°C
cavity height	H =	3.010	m
cavity width	D =	0.172	m
cavity length	L =	1.000	m
cavity section	$A_c =$	0.172	m ²
cavity volume	$V_c =$	0.518	m ³
inlet height	$h_1 =$	0.010	m
inlet surface	$A_1 =$	0.010	m ²
inlet local friction factor	$\xi_1 =$	0.5	-
outlet height	$h_2 =$	0.010	m
outlet surface	$A_2 =$	0.010	m ²
outlet local friction factor	$\xi_2 =$	1.0	-
air properties			
environmental air density	$\rho_e =$	1.19	kg/m ³
cavity air density	$\rho_i =$	1.18	kg/m ³
cavity air dynamic viscosity	$\mu_i =$	1.85E-05	Pa.s
cavity air kinematic viscosity	$\nu_i =$	1.56E-05	m ² /s
cavity air specific heat	$c_{pi} =$	1007	J/kg.K
cavity air thermal conductivity	$\lambda_i =$	0.026	W/m.K
cavity air thermal diffusivity	$\alpha_i =$	2.181E-05	m ² /s
Prandtl number	Pr =	0.715	-
air flow results			
hydraulic diameter	$D_h =$	0.294	m
pressure difference caused by density difference	$\Delta p =$	0.24	Pa
pressure difference caused by friction losses	$\Delta p =$	0.24	Pa
air velocity in the cavity	v =	0.03	m/s
air velocity in the inlet	$v_1 =$	0.51	m/s
air velocity in the outlet	$v_2 =$	0.51	m/s
air flow	$Q_m =$	0.005	m ³ /s
air flow	$Q_m =$	18.54	m ³ /h
coefficient b in $Q_m = b \cdot \Delta\theta ^{0.5}$	b =	0.00364	m³/sK^{0.5}
ventilation rate	n =	35.81	/h
heat flow in case of linear temperature gradient in cavity	$Q_{Tlinear} =$	25	W
heat flow in case of homogeneous temperature in cavity	$Q_{Thomogeneous} =$	12	W

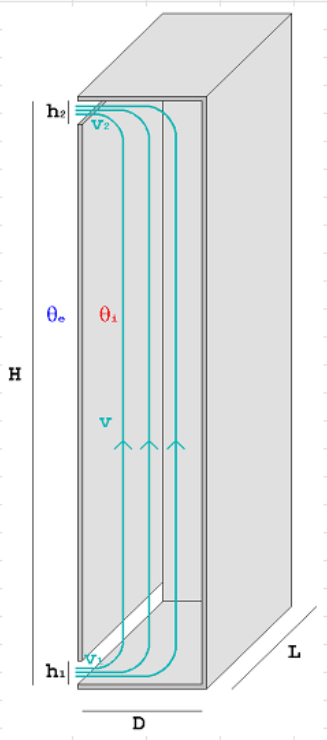


Figure 13 Stack effect calculation spreadsheet file [T VTR b air cavity stack effect.xlsm](#)

Step 1

A first VOLTRA simulation is done using a constant ventilation flow (Section 3). Control effects are not considered for this exercise so the user can delete the control function or continue with the [T_VTR_b_Constant_ventilation_flows_corrected.vtr](#) file.

Step 2

The result report is pasted into sheet 1 of the file [T_VTR_b_varying_ventilation_flow.xlsx](#) (Figure 14). In the final column, the mass flow is calculated using the formula presented above, based on the outdoor temperature and the temperature of the third cavity partition, which is assumed to represent the approximate average cavity temperature.

The calculated mass-flow values for the cavities are then copied into the file [VENT_FLOW.FVR](#) (a text file that can be edited using MS Excel.) The simplest approach is to write "FVR" in an adjacent column next to each flow rate value, then copy the complete list and paste it into Notepad before saving [VENT_FLOW.FVR](#).

	h	outdoors	indoors air	single glaz	floor 1	floor 2	comfort fa	comfort cc	cav 1	cav 2	cav 3	cav 4	cav 5	FVR	m ³ /s
0000:00:00:00	0.00	17.7	23.5	22.1	24.7	23.7	23.4	23.6	18.2	18.6	18.9	19.3	19.5	FVR	0.004150
0000:00:10:00	0.17	17.6	23.5	22	24.6	23.7	23.3	23.5	18.1	18.5	18.9	19.2	19.4	FVR	0.004150
0000:00:20:00	0.33	17.5	23.4	21.9	24.6	23.7	23.2	23.4	18	18.4	18.6	19.1	19.2	FVR	0.004150
0000:00:30:00	0.50	17.4	23.3	21.7	24.5	23.6	23.2	23.4	17.9	18.3	18.7	19	19.1	FVR	0.004150
0000:00:40:00	0.67	17.3	23.3	21.6	24.4	23.6	23.1	23.3	17.8	18.2	18.6	18.9	19	FVR	0.004150
0000:00:50:00	0.83	17.2	23.2	21.6	24.4	23.6	23	23.3	17.7	18.1	18.5	18.8	18.9	FVR	0.004150
0000:01:00:00	1.00	17.1	23.1	21.5	24.3	23.5	23	23.2	17.6	18	18.4	18.7	18.8	FVR	0.004150
0000:01:10:00	1.17	16.9	23.1	21.4	24.3	23.5	22.9	23.1	17.4	17.8	18.2	18.5	18.7	FVR	0.004150
0000:01:20:00	1.33	16.7	23	21.3	24.2	23.4	22.8	23.1	17.2	17.6	18	18.4	18.5	FVR	0.004150
0000:01:30:00	1.50	16.5	23	21.2	24.2	23.4	22.8	23	17	17.5	17.9	18.2	18.3	FVR	0.004307
0000:01:40:00	1.67	16.3	22.9	21.1	24.1	23.4	22.7	23	16.8	17.3	17.7	18	18.2	FVR	0.004307
0000:01:50:00	1.83	16.1	22.9	21	24	23.3	22.6	22.9	16.6	17.1	17.5	17.9	18	FVR	0.004307
0000:02:00:00	2.00	15.9	22.8	20.9	24	23.3	22.6	22.9	16.5	16.9	17.3	17.7	17.9	FVR	0.004307

Figure 14 Ventilation flow calculation using the file [T_VTR_b_varying_ventilation_flow.xlsx](#)

Step 3

Now the VOLTRA model can be adjusted: the constant ventilation flow is replaced by the time dependent function [VENT_FLOW.FVR](#).

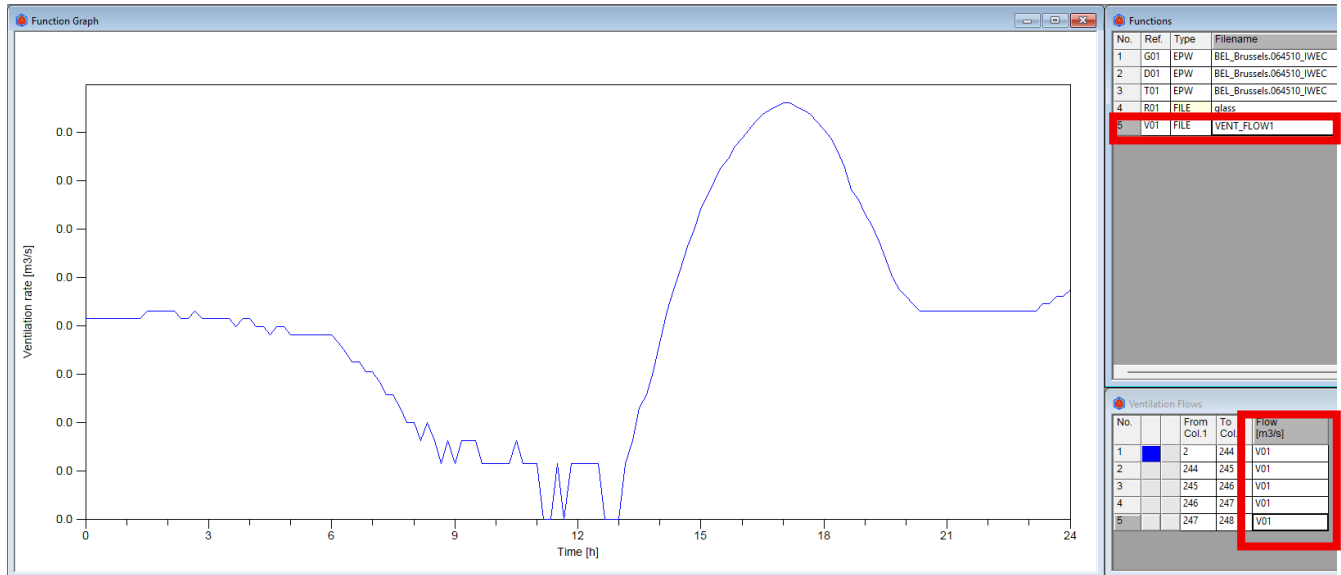


Figure 15 Ventilation flow function in VOLTRA

Step 4

Step 2 and 3 are repeated until minor further temperature changes are reached. See the sheets and charts 2-8 in the file [T_VTR_b_varying_ventilation_flow.xlsx](#). For each case, the newly calculated flow-rate values are copied into [VENT_FLOW.FVR](#) using Notepad and the updated file is then re-uploaded into the VOLTRA model. If this workflow becomes confusing, it is recommended to save the files with iteration numbers at each step to keep track of the progress.

The final temperature evolutions are presented in Figure 16 Temperature for specified points.

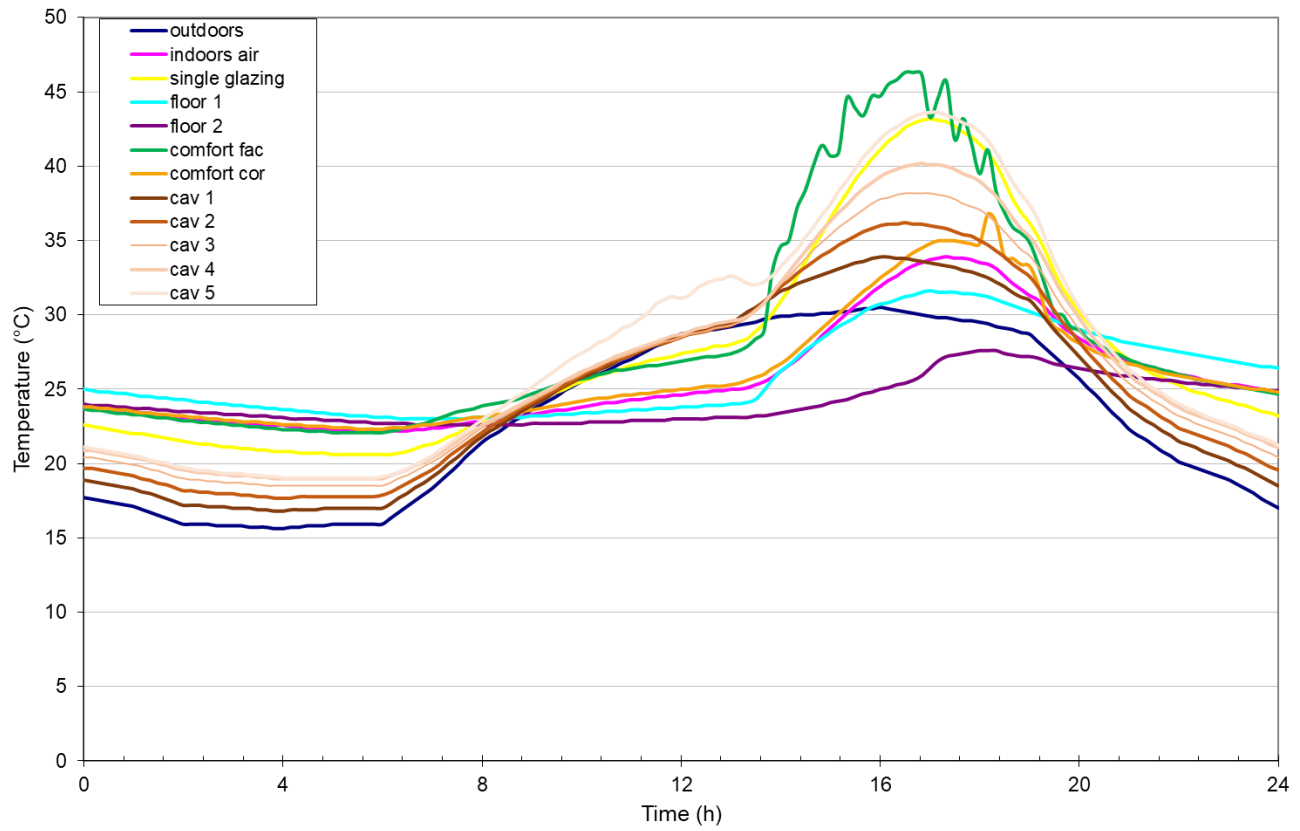


Figure 16 Temperature for specified points