TUTORIAL

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

VTR TUTORIAL B

1. Introduction

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 continue using the final model from the previous exercise T_VTR_a_solar_double_skin_facade_b_fine_grid.vtr.

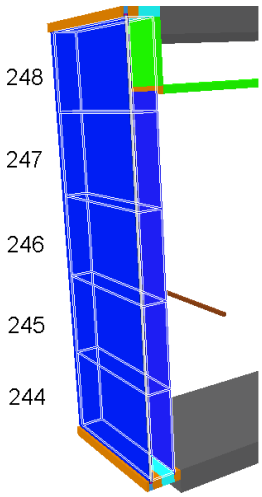
In this tutorial, we build on the earlier model by adding several enhancements to demonstrate forced and natural convective ventilation flows and control-function mechanisms within the double skin façade system.

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.



Blocks

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

Colours

Col.		Type	Subtype	Name	ε1 / ε2 [- / -]	ε [-]	ρ [kg/m³]	c [J/kgK]	θ [°C]	h [W/m²K]	q [W/m²]	θa [°C]	hc [W/m²K]	Pc [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

Figure 1 Changes in the model to define ventilation flow

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 2 shows the positions of added sensor positions. Figure 3 displays the grid modifications. Figure 4 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.

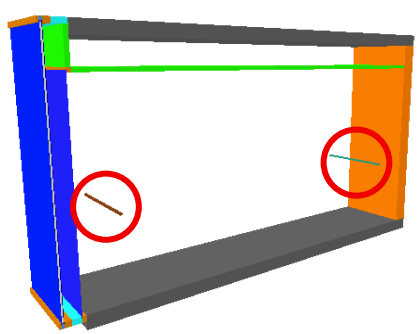


Figure 2 Comfort temperature sensors

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 3 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/m³]	c [J/kgK]	ρs [-]	τs [-]
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 4 Block numbers and material properties of comfort temperature sensors

2 new output nodes are added on these sensors

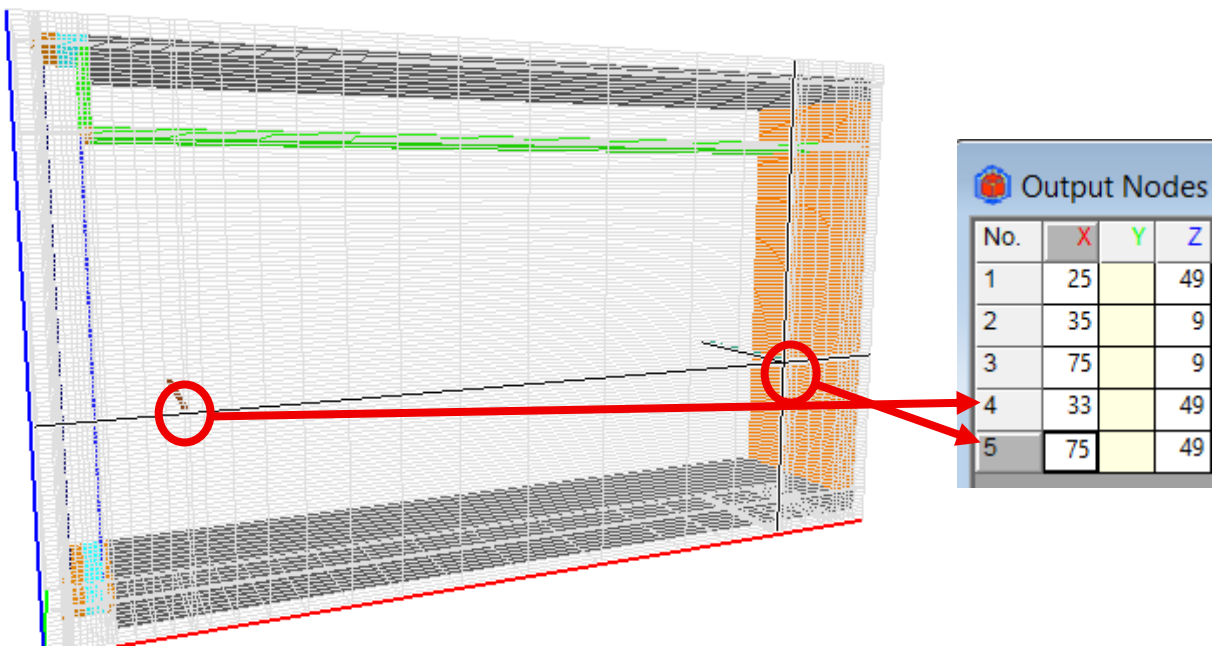


Figure 5 Output nodes

3. Constant ventilation flow

T_VTR_b_constant_ventilation_flow_corrected.vtr

Figure 6 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 row 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) do not have to be adjacent.

In this example, ventilation with outdoors air with a constant flow of 0.017 m^3/s is assumed. It enters the facade through bottom and goes upward. It is not necessary to specify where to the air from the zone 248 flows, as this doesn't affect the thermal behaviour of the object considered.

Ventilation Flows

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 6 Ventilation flows

Figure 7 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 8 shows the results.

Report Definition

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 7 Report definition

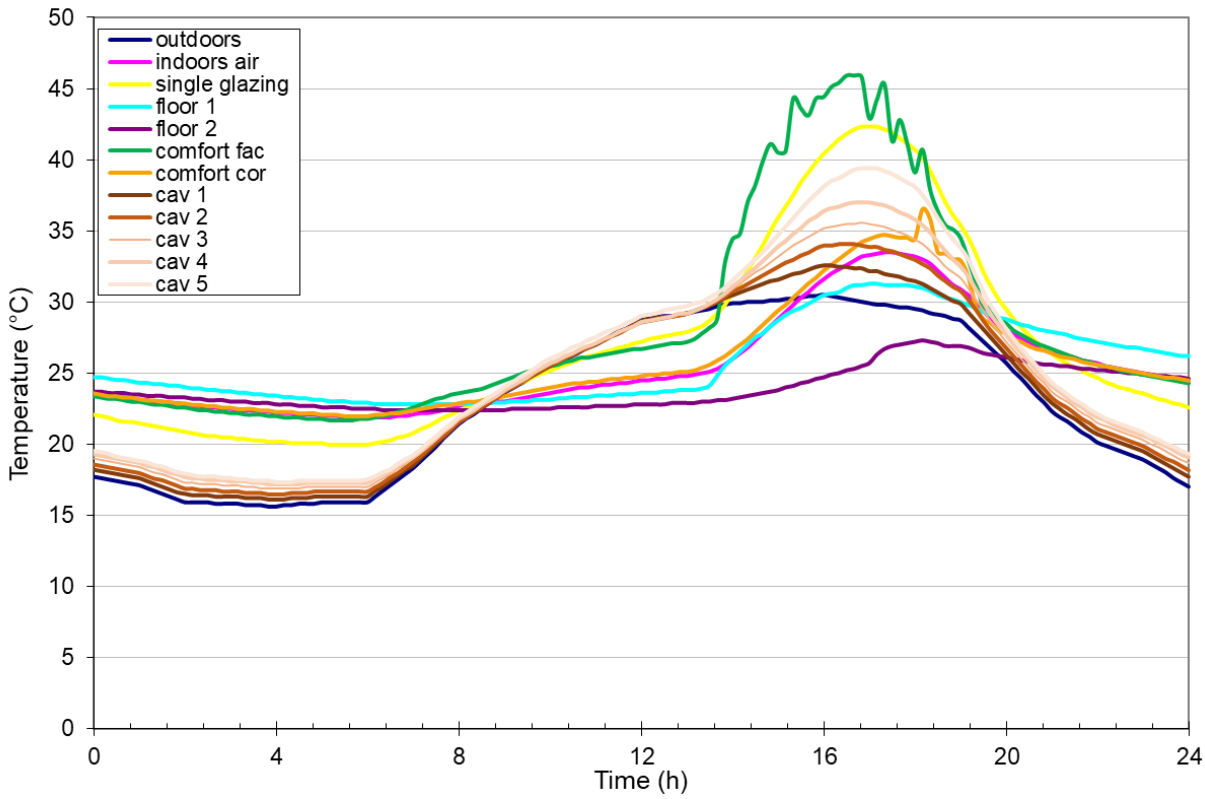


Figure 8 Temperature for specified points

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 9 displays the parameters related to controls.

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 9 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 10(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 10(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.

Functions

No.	Ref.	Type	Filename	Prm.1
5	T02	CONST		23
6	V01	CONST		0
7	V02	CONST		0.017

Ventilation Flows

No.			From Col.1	To Col.2	Flow [m3/s]
1			2	244	V01
2			244	245	V01
3			245	246	V01
4			246	247	V01
5			247	248	V01

Figure 10 left) New functions for controls and right) Ventilation flows window with functions

If **Test Δθ** 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:
    - 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.

Report Definition

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 11 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 11.

Figure 12 illustrates the results with control actions and Figure 13 shows the control state in the calculation period.

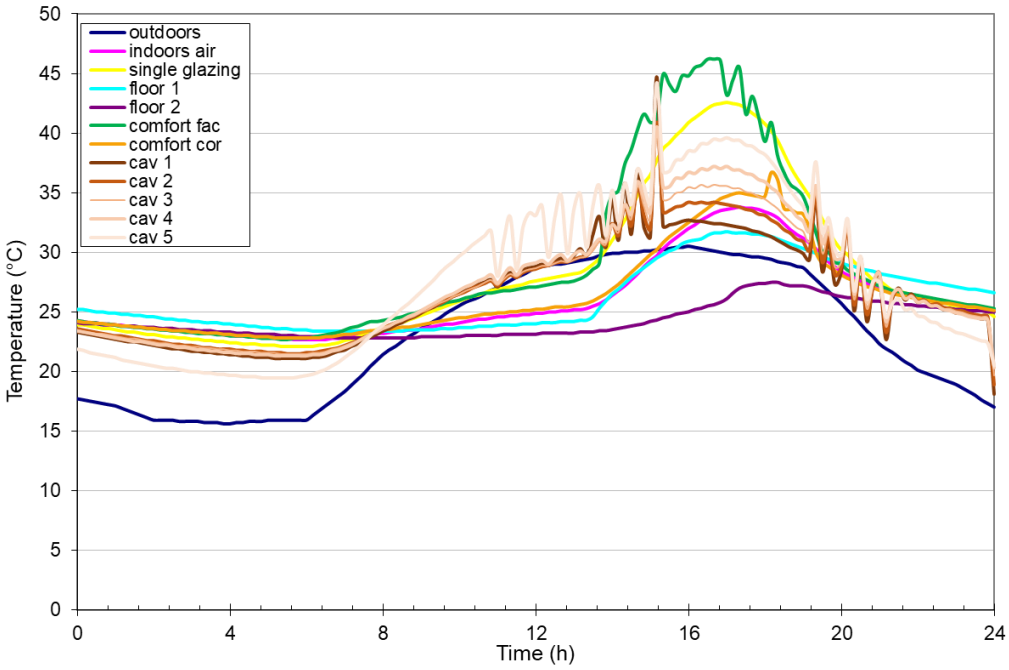


Figure 12 Temperature for specified points

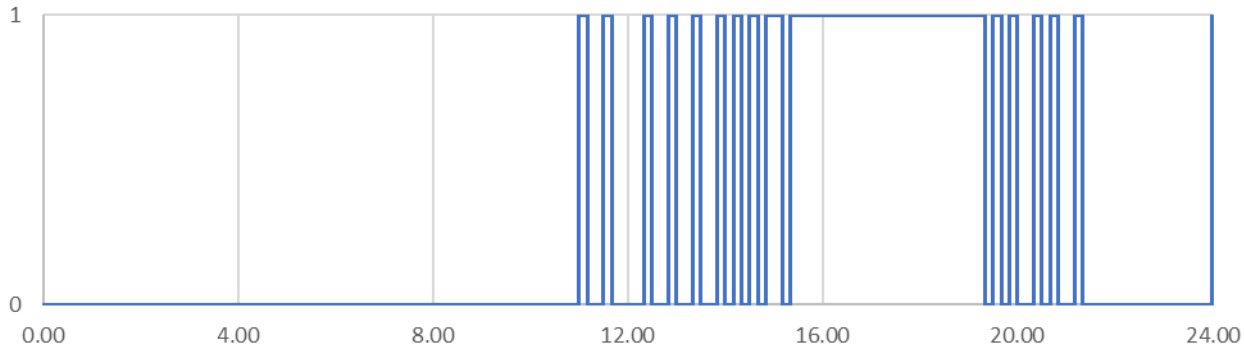


Figure 13 Control state vs time

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 13:30 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 (Section 3) 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 14) 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)

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

b[m3/sK0.5] 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.

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

Calculation of thermal-driven ventilation through an air cavity with a rectangular cross section

To use this sheet properly, Ecxel add-inn solver shoule be installed

environmental temperature	θ_e =	23.0	°C
cavity temperature	θ_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	ξ_1 =	0.5	-
outlet height	h_2 =	0.010	m
outlet surface	A_2 =	0.010	m^2
outlet local friction factor	ξ_2 =	1.0	-
air properties			
environmental air density	ρ_e =	1.19	kg/m^3
cavity air density	ρ_i =	1.18	kg/m^3
cavity air dynamic viscosity	μ_i =	1.85E-05	Pa.s
cavity air kinematic viscosity	ν_i =	1.56E-05	m^2/s
cavity air specific heat	c_{pi} =	1007	J/kg.K
cavity air thermal conductivity	λ_i =	0.026	W/m.K
cavity air thermal diffusivity	α_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	Δp =	0.24	Pa
pressure difference caused by friction losses	Δp =	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 $Q_m = b * \lvert\Delta\theta\rvert^{0.5}$	b =	0.00364	$m^3/sK^{0.5}$
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

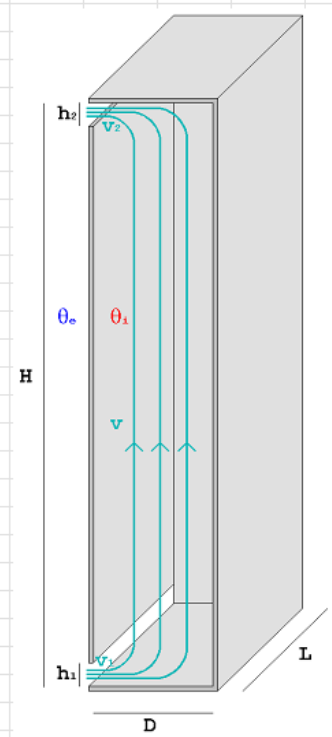


Figure 14 Stack effect calculation spread sheet file T_VTR_b_air_cavity_stack_effect.xlsm

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 15). 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		m3/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	19	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	18.8	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 15 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.

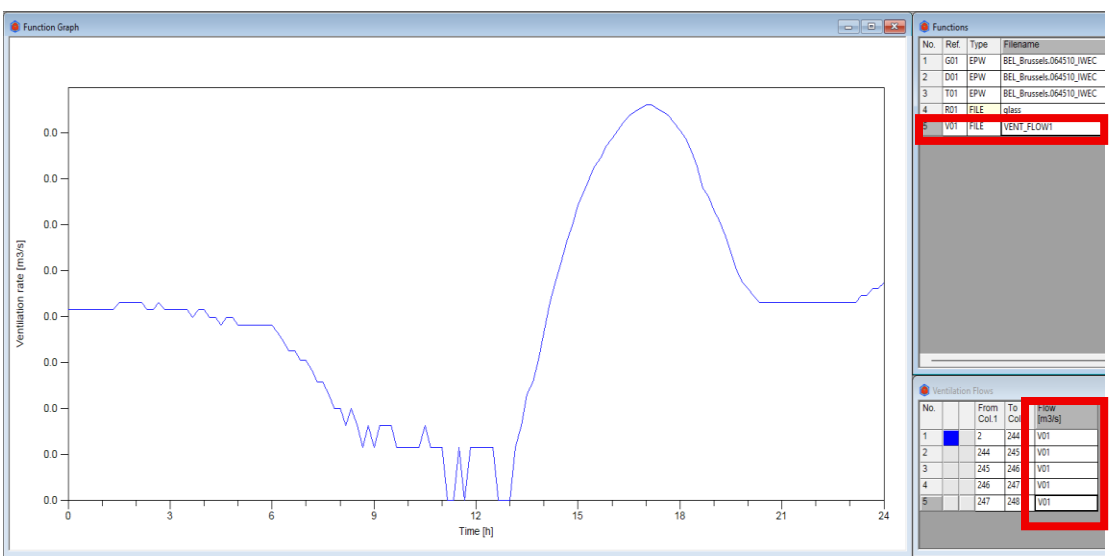


Figure 16 Ventilation flow function in VOLTRA

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 17 Temperature for specified points.

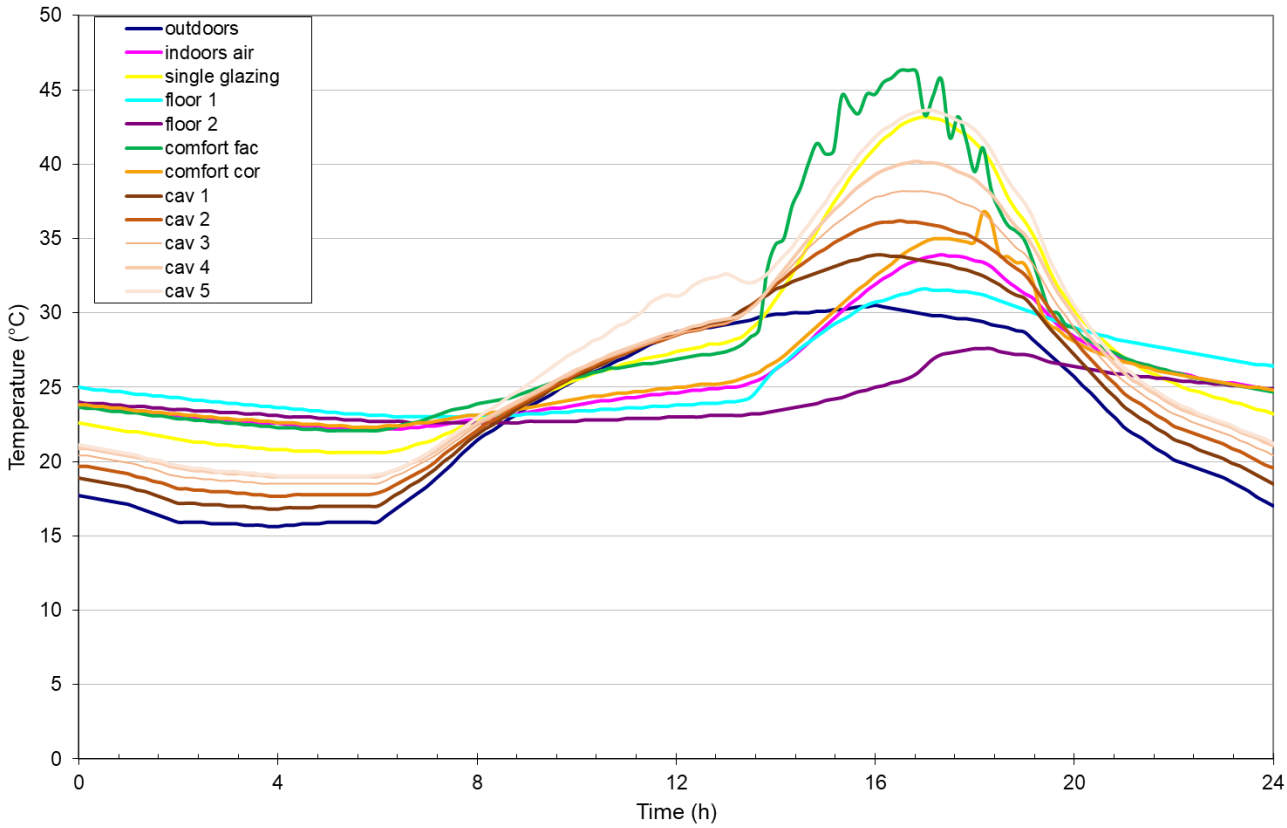


Figure 17 Temperature for specified points